11-27-2018

A Comparison of Two Tai Chi Interventions Tailored for Different Health Outcomes

Yin Wu
University of Connecticut - Storrs, yin.2.wu@uconn.edu

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Yin Wu, PhD

University of Connecticut, [2018]

Tai Chi has demonstrated salutary health benefits, but whether tai chi interventions tailored for specific health outcomes will result in different health benefits remains unknown. Therefore, we compared the health benefits of two different Tai Chi interventions targeted for improvements in either blood pressure (BP) (PRESSURE) or balance (BALANCE). We tailored PRESSURE to emphasize breathing techniques and mental relaxation and BALANCE to emphasize movement principles that challenged balance. Subjects were randomized to PRESSURE (n=12), BALANCE (n=13), or CONTROL (n=10). Tai Chi was practiced 3 sessions/wk, 60 min/session for 12 wk. CONTROL performed daily activities. We tested the change in cardiometabolic health, balance, and functional fitness outcomes among groups with analyses of covariance with the health outcome baseline value, age, and body mass index as covariates adjusted for multiple comparisons. Subjects were physically active, Tai Chi naive (97.1%), white and older (78.9±5.7yr) with systolic BP (SBP) of 126.5±14.4 mmHg and diastolic BP of 69.3±8.4mmHg, and mostly female (82.9%). PRESSURE improved Chair Sit-to-Stand Test (CSTS) (1.0±1.8 vs. -0.6±0.8times/30sec, P=.03) versus CONTROL, and gait speed (12.8±43.3 vs. -24.1±22.4cm/sec, P=.02) versus BALANCE. Meanwhile, BALANCE improved Single Leg Stance Test (5.4±18.0 vs. -8.2±10.3sec, p=.049) and CSTS (1.0±1.7 vs. -0.6±0.8times/30sec, p=.03), and tended to lower SBP (-4.2±16.0 vs. 3.5±8.3mmHg, p=.052) versus CONTROL. Within just 3 months, physically active, Tai Chi naive older adults improved on a variety of health outcomes, independent of the type of Tai Chi practice. Future studies should confirm our findings and determine the sustainability of the accrued health benefits with a longer period of Tai Chi practice among a larger, more ethnically and gender diverse sample.

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Yin Wu

B.A., China Pharmaceutical University, **[2009]**

M.A., Georgia State University, **[2012]**

A Dissertation

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

at the

University of Connecticut

[2018]

APPROVAL PAGE

Doctor of Philosophy Dissertation

A Comparison of Two Tai Chi Interventions Tailored for Different Health Outcomes

Presented by

Yin Wu, B.S., M.A.

Major Advisor

Linda S. Pescatello

Associate Advisor

Beth A. Taylor

Associate Advisor

Crystal L. Park

Associate Advisor

Susan S. Glenney

Associate Advisor

Richard H. Fortinsky

University of Connecticut
[2018]

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Chapter 1. Problem Statement

Background and Significance

Population Aging and Health Care in the United States

The current growth in the number and proportion of older adults in the United States (US) is unprecedented in history. By 2030, approximately 20% (~72 million) of the American population will consist of older adults.[1, 2] By 2050, it is estimated that there will be ~90 million Americans aged 65 or older, twice the number of older adults in the US as in 2010.[3]

Both the physiological and psychological aging processes increase the risks for many musculoskeletal, neurocognitive, cardiovascular, and metabolic diseases and health conditions (e.g., coronary artery disease, osteoporosis, dementia).[4,5] As a result, comorbidities are highly prevalent among older adults such that by the age of 65 years more than 60% of adults will have two or more chronic conditions, more than 25% will have four or more chronic conditions, and almost 10% will have six or more.[6]

Due to the prevalence of comorbidity, the cost of providing health care for an older adult is three to five times higher than the cost for someone younger than 65 years.[7] The health care budget of older adults currently is about 65% of the country's total budget.[8] By 2030, health care spending for all Americans will increase by 25% largely due to population aging,[9] and Medicare spending is projected to increase from $555 billion in 2011 to $903 billion in 2020.[10]

Older Adults and Physical Activity

Because of the increased risk for chronic disease and health conditions and the high costs of health care of the aging population in the US, it is imperative to investigate low cost and effective lifestyle interventions as adjuvants to pharmaceutical and surgical treatments.[11] Physical activity in particular is one of most effective ways to improve overall health, chronic disease risk factors, and quality of life.[12] For the older adult population there are considerable nuances in the *F*requency, *I*ntensity, *T*ime, and *T*ype (*FITT*) principle of exercise prescription (Ex R_x).[13] Despite this fact, the consensus among various professional recommendations[12,14-17] is for older adults to participate in 30 minutes/day or more of moderate intensity aerobic exercise for at least 3-5 days/week to total 150 minutes/week supplemented by resistance (≥2 days/week at moderate intensity), flexibility (≥2 days/week), and neuromotor exercise.

Despite the knowledge of the many health benefits that result from regular participation in physical activity, many older adults remain physically inactive. In 2010, [18] about 90% of older adults ≥65 years, and over 95% of older adults ≥85 years did not meet the aerobic activity and muscle-strengthening recommendations.[12,14-17] Therefore, it is important to explore exercise options that have high acceptability to older adults in attempts to reduce this high amount of physical inactivity.

Tai Chi Exercise for Older Adults

Tai Chi was originally created in China as a form of martial arts nearly 400 years ago and was practiced mainly for combat purposes.[19] Over its long evolutionary process, Tai Chi developed into five major styles (Chen, Yang, Sun, Wu, Hao) and more than 108 forms.[19,20] In 1956, the Chinese government simplified Tai Chi practice by creating a 24-form Yang-style Tai Chi routine that became available for public use as a form of exercise.[19] Interestingly, from the time of its conception to now, Tai Chi were not has not been designed to target any specific health outcomes.[20]

Tai Chi is low intensity, social, and enjoyable form of neuromotor exercise. These features have all been identified as motivators for older adults to be physically active,[21-24] and increase the acceptability of exercise among older adults.[25] First, the intensity of Tai Chi practice is low with a metabolic energy equivalent (MET) ranging from 1.5 to 3 METs,[26] with movements that are slow and smooth.[27] The risk of serious injury from practicing is very low with no study having reported serious injuries from Tai Chi practice.[28,29] Second, Tai Chi exercise promotes social interaction as it is commonly offered in community centers in group classes led by instructors.[30,31] Last, Tai Chi exercise is enjoyable as a choreographed exercise,[32] and well received by older adults in research studies.[33] For these many reasons, Tai Chi is an exercise option that has the potential to be very attractive to older adults.

Surprisingly, according the 2012 National Health Interview Survey, only 1.2% of the older adults who responded (n=69,149) had participated in Tai Chi in the past 12 months.[34] To promote Tai Chi among older adults, one of the most effective ways is for health care and fitness professionals to recommend Tai Chi and to explain the acute and chronic benefits of Tai Chi exercise.[25] In order to do so, health care and fitness professionals need to understand what are the most appropriate Ex R_x and instructional methods (e.g., style of Tai Chi, breathing techniques) of Tai Chi for the targeted health benefits.[35] Unfortunately, such knowledge has yet to be produced due to the fact that much of the scientific community is unaware of the need of tailoring the FITT Ex R_x and instructional methods of Tai Chi for the health outcomes being targeted,[36,37] For example, balance improvement and blood pressure (BP) reduction are the two most studied health benefits of Tai Chi ,[27,28] because they are both priorities in order to "improve the health, function, and quality of life of older adults" according to Healthy People 2020.[38] Nevertheless, Tai Chi interventions were rarely tailored for balance improvement or BP reduction in research studies investigating these health outcomes.[37]

Balance Improvement and Tai Chi Exercise

Approximately 30% of healthy older adults experience a fall annually, largely due to age-related decrements in balance.[39] Falls are the leading cause of fatal injury and the most common cause of nonfatal trauma-related hospital admissions among older adults.[40,41] The number of fatal falls, non-fatal fall related injuries, and medical expenses related to falls is increasing rapidly. In 2000, there were ~10,000 fatal falls and 2.6 million medically treated non-fatal fall related injuries with associated medical expenses totaling over $19 billion.[42] In 2012, there were ~24,000 fatal falls and 3.2 million medically treated non-fatal fall related injuries with associated medical expenses totaling over $30 billion.[43] Due to aging population, the total medical expense related to falls is expected to reach $68 billion by 2020.[44]

In general, Tai Chi has been shown to be effective at improving balance in a diverse sample of older adults, but such improvements are not consistent across studies.[37,45-49] Researchers have speculated that the widely varying Ex R_x and instructional methods reported in Tai Chi interventions are the primary contributors to the inconsistencies in this literature.[45-49] Our research team reviewed Tai Chi trials aimed at improving balance for older adults (k=28) and found that investigators rarely customized their Tai Chi interventions for the health outcome being targeted. For, the instructional methods most important for tailoring Tai Chi practice to improve balance[50] were routinely not disclosed with only 15% reporting the names of Tai Chi forms and 52% reporting movement principles. In addition, the same review found that among all the FITT Ex R_x (e.g., frequency, time of Tai Chi exercise sessions, and length of the intervention) and instructional methods (e.g., style of Tai Chi, credential of instructors, and breathing techniques), only the reporting of movement principles was marginally correlated with balance improvements following Tai Chi exercise ($r=0.35$, $p=.08$).[37] It still remains largely unknown what are the most appropriate FITT Ex R_x and instructional methods of Tai Chi to improve balance.

Blood Pressure Reduction and Tai Chi Exercise

Hypertension is the most prevalent and treatable cardiovascular disease (CVD) risk factor. Each 20-mmHg increment in systolic BP (SBP) and 10-mmHg increment in diastolic BP (DBP) increases and eventually doubles the risk of mortality from CVD.[51] Conversely, BP reductions of 5-10 mmHg lower the incidence of CVD by 20-40%.[51] According to the Seventh Report of the Joint National Committee (JNC7) criteria,[52] hypertension (SBP≥140 and/or DBP≥90 mmHg) affects approximately 1 billion (40.0%) adults ≥25 years of age worldwide and 86 million (34.0%) adults ≥18 years of age in the US.[53-55] In addition, hypertension results in about 9 million deaths globally and ~73,000 deaths annually in the US.[53,55] Of note, due to the significant public health burden of hypertension, the 2017 American College of Cardiology and American Heart Association Guidelines lowered the threshold of hypertension to ≥130 mmHg for SBP or ≥80 mmHg for DBP;[56] accordingly, 75 to 85% of older adults (≥65 years) in the US now classified as having hypertension.[56]

In general, Tai Chi is effective at reducing BP in diverse samples of adults.[57,58,59] In fact, Tai Chi has been reported to elicit SBP reductions as large as ~17-19 mmHg and DBP reductions as large as ~11-13 mmHg in primary level intervention Tai Chi studies published in English and Chinese.[60-62] However, the meta-analysis from our research group found that (see chapter 3-B) studies (*n*=31) rarely disclosed the intensity of Tai Chi exercise (only 3.2% did), breathing techniques (only 22.7% did), and relaxation (only 9.7% did), all features of Tai Chi that could influence the BP response to Tai Chi. In addition, there was not enough variation in some of the features of Tai Chi among included trials. For example, we were not able to examine the influence of time of Tai Chi sessions over the BP response to Tai Chi because about 80 percent of the Tai Chi sessions lasted 50 to 65 minutes.

The inconsistency of the literature and the lack of customization of Tai Chi exercise for specific health outcomes, particularly balance and BP, emphasizes the need for additional interventional studies specifically designed to target balance improvement and reduce BP to determine not only the optimal FITT Ex R_x, but also the combination of instructional methods that maximize the effectiveness of Tai Chi exercise for these health outcomes.

Purpose of the Study

Therefore, we conducted a 12-week Tai Chi intervention study. In this study, we tailored the FITT Ex R_x and instructional methods of two different Tai Chi interventions. One Tai Chi intervention was tailored for the targeted health outcome of balance (BALANCE), and the other Tai Chi intervention was tailored for the targeted health outcome of BP (PRESSURE).

Specific Aims and Hypotheses

The primary purpose of the study is to directly compare the effectiveness of BALANCE and PRESSURE in terms of improving balance and lowering BP.

<u>Specific aim 1</u>**:** to directly compare the effectiveness of BALANCE and PRESSURE in terms of improving balance versus control. We *hypothesize* that the improvement in static balance measured by the Single Leg Stance Test, and the improvement in dynamic balance measured by the Four Square Step Test would be significantly larger in BALANCE than PRESSURE.

<u>Specific aim 2</u>**:** to directly compare the effectiveness of BALANCE and PRESSURE in terms of lowering BP. We *hypothesize* that the reduction of SBP and DBP would be significantly larger in PRESSURE than BALANCE.

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Chapter 2-A. Healthy Aging and Exercise: Preventing Disease and Disability

Abstract: Exercise provides numerous physiological and psychological benefits for healthy older adults. However, most older adults in the United States are physically inactive. This chapter first summarizes the evidence demonstrating the resultant health benefits from exercise based on both epidemiological and interventional research. Second, this chapter introduces the concept of exercise prescription, presents the physical activity guidelines for older adults from various professional committees and organizations, and discusses special considerations when prescribing exercise for older adults. Last, this chapter highlights several of the behavioral theories that can be used to increase physical activity and reduce sedentary behavior among older adults.

Keywords: behavioral theory, exercise prescription, older adults, physical activity, sedentary behavior

Table of Abbreviations

Listed by the order of appearance in text

US	United States
WHO	World Health Organization
T2DM	Type 2 diabetes mellitus
QoL	Quality of life
ADL	Activities of daily living
SBP	Systolic blood pressure
Ex R_x	Exercise prescription
ACSM	American College of Sports Medicine
GETP10	Guidelines for Exercise Testing and Prescription 10th Edition
MET	Metabolic equivalents
HBM	Health Belief Model
PAGAC	Physical Activity Guidelines Advisory Committee
CSEP	Canadian Society of Exercise Physiology
BHFC	British Heart Foundation Centre
OA	Osteoarthritis
HBM	Health Belief Model
CVD	Cardiovascular disease
DM	Diabetes mellitus
BMI	Body mass index
PCP	Primary care physician
BP	Blood pressure

1. Population Aging and Implication on Healthcare

The current growth in the number and proportion of older adults in the United States (US) and worldwide is unprecedented. By 2030, older adults (≥65 years) will comprise approximately 20% (~72 million) of the American population.[1, 2] By 2050, it is estimated that there will be ~90 million Americans 65 years or older, twice the number of older adults in the US as in 2010.[3] According to the World Health Organization (WHO), between 2015 and 2030, the number of older adults (≥60 years) in the world will increase by 56%, from 901 million to 1.4 billion. By 2050, the global population of older adults will reach 2.1 billion, more than double its size in 2015.[4]

Both the physiological and psychological processes of aging increase the risks for many cardiovascular, pulmonary, metabolic, musculoskeletal, and neurocognitive diseases/conditions (e.g., hypertension, coronary artery disease, osteoporosis, dementia).[5,6] As a result, comorbidities are highly prevalent among older adults. In the US, more than 66% of older adults have two or more chronic diseases or health conditions, more than 35% will have four or more chronic diseases or health conditions, and almost 15% will have six or more.[7] The cost of providing health care for an older adult is three to five times higher than the cost for someone younger than 65 years in the US, largely due to the prevalence of these comorbidities.[8] Consequently, the health care budget for older adults currently is about 65% of the country's total healthcare budget.[9] By 2030, health care spending for all Americans will increase by 25% largely due to population aging.[10]

Because of the increased risk for chronic diseases and health conditions and the high costs of health care for an aging population, it is imperative to investigate low cost, effective lifestyle interventions to support and even mitigate the need for more expensive pharmaceutical and surgical treatments.[11]

2. Physical Activity and Healthy Aging

Physical activity is any bodily movement that is produced by the skeletal muscles and results in energy expenditure;[12] it can occur in any form such as leisure time physical activity, household chores, and traveling to and from work.[13] In addition, when used by itself, the term physical activity encompasses all types and intensities of physical movement from walking and gardening, to moving heavy furniture. The WHO recommends adults and older adults perform at least 150 minutes of moderate intensity aerobic physical activity, and muscle-strengthening activity on two or more days per week.[13] Not meeting these WHO recommendations is defined as being physical inactive; and globally, physical inactivity causes 9% of premature mortality, and 6 to 10 % of the burden of chronic disease including coronary heart disease, type 2 diabetes mellitus (T2DM), and breast and colon cancer.[14]

For decades, epidemiology studies have demonstrated numerous benefits of regular physical activity, such as reducing chronic disease risk, improving functional status, and improving quality of life (QoL).[15] For example, Jefferies and colleagues followed 3,357 men (mean age: 68.3 years) over 11 years and found that compared with walking 0 to 3 hours/week, walking 4 to 7, 8 to 14, 15 to 21, and >22 hours/week was associated with reduced risk of stroke by 11%, 37%, 32%, and 64%, respectively.[16] Blondell and colleagues meta-analyzed 47 cohort studies among adults aged 40 and older, and found that having higher levels of physical activity was associated with a 35% lower risk of cognitive decline, and 14% lower risk of dementia compared to having lower levels of physical activity.[17] Tak and colleagues meta-analyzed nine longitudinal studies to investigate the relationship between physical activity level and the incidence of developing disability in performing Activities of Daily Living (ADL) among older adults (mean age: 70.9 to 77.8 years when reported). These authors found that older adults who regularly engage in moderate intensity physical activity reduced their risk of developing disability in performing ADLs by 49%.[18] Lastly, in a recent cohort study, Koolhaas and colleagues recruited 5,554 middle-aged and older adults to investigate the relationship between physical activity and health-related quality of life. They found a dose-response relationship between total physical activity and better health-related QoL for older adults. For example, compared to being sedentary, being physically active for about 4 hours per day was associated with a 67% lower risk of mobility problems, and a 43% lower risk of mood problems among older adults.[19]

Globally, the average life expectancy has increased dramatically in the 20th century, and has increased by 5 years since 2000.[20] However, a greater life expectancy does not necessarily entail a concomitant increase in disease-free life expectancy, since older adults experience an increased burden of chronic disease and disability.[21,22] Therefore, healthy aging becomes an important concept within which to consider the optimization of physical function during the human lifespan. Healthy aging is defined by the WHO as the process of developing and maintaining the functional ability that enables wellbeing in older age.[21] Although there is still no consensus regarding a definition of healthy aging,[23] a recent meta-analysis showed that based on 23 cohort studies (N=174,114), physical activity was positively associated with healthy aging (effect size: 1.39, 95% CI = 1.23–1.57).[24] Specifically, the on-going English Longitudinal Study of Aging has already demonstrated that participants who engage in moderate or vigorous intensity physical activity at least once a week exhibit a reduced risk of T2DM,[25] greater muscular strength,[26] fewer depressive symptoms,[27] and eventually, a greater chance of healthy aging compared to inactive participants. These authors defined healthy aging as having survived until the 8-year follow-up without developing major chronic disease, depressive symptoms, physical or cognitive impairment.[28]

3. Benefits of Exercise among Older Adults

Exercise is a subset of physical activity which is planned, structured, repetitive and aims to maintain and improve physical fitness.[12,24] Numerous intervention studies have shown that exercise leads to positive physiological and psychological changes in multiple systems of the human body that can delay and sometimes reverse the negative changes that occur with advanced aging. Several specific examples are described below, and Table 1 further describes the influence of exercise on the primary aging-related changes on cardiovascular function,[29-37] muscular function,[38-49] pulmonary function,[39,43] body composition and metabolism[50-52] and cognitive function.[53-57]

[INSERT TABLE 1 HERE]

Colcombe and colleagues recruited 59 healthy but sedentary community-dwelling older adults (mean age: 65.5 years). The participants were assigned to either an exercise group that attended 1-hour moderate intensity aerobic exercise sessions for 3 days/week, or a control group performing toning and stretching exercises. After six months, authors found significant increases in brain volume in both the gray and white matter regions in the exercise but not control group.[54] McCartney and colleagues examined the benefits of 42 weeks of dynamic resistance exercise training among 142 healthy adults 60–80 years. The participants in the exercise group performed resistance exercise training twice per week for 42 weeks at moderate intensity, while participants in the control group performed only their usual daily activities. There were significant gains (up to 65% relative to baseline) in maximum muscle strength accompanied by smaller gains (up to

5.5% relative to baseline) in muscle size in knee extensor muscles in the exercise group, while there was no change in the control group.[58] In addition, the participants in the exercise group improved their peak cycling power output and treadmill walking endurance significantly more than participants in the control group (7.1% vs. 1.1%, and 17.8% vs. 3.4% improvement, respectively).[58] Wolf and colleagues recruited 200 community-dwelling older adults (mean age: 76.2 years) and randomly assigned participants into 15 weeks of Tai Chi, computerized balance training or an education control groups. Only the participants in the Tai Chi groups significantly reduced systolic blood pressure (SBP) (~14 mmHg). Participants in the Tai Chi group also reduced the fear of falling (p=0.046), and 48% reduced the risk of multiple falls (p=0.01) relative to the education control group.[59]

Overall, both epidemiology studies that investigated the relationship between physical activity level and chronic disease risk, functional status, and QoL, and intervention studies that examined the health benefits (e.g., improving cardiorespiratory fitness) of exercise demonstrate that, to achieve healthy aging, it is crucial for older adults to stay physically active.

4. Exercise Prescription for Older Adults

As introduced above, there is overwhelming evidence demonstrating the health benefits of regular physical activity/exercise participation among older adults. However, many older adults remain physically inactive.[60] In 2010, about 90% of older adults ≥65 years, and over 95% of older adults ≥85 years did not meet the aerobic and resistance physical activity recommendations in the US.[61-63] Health care and exercise professionals have the unique opportunity to promote exercise participation among their older patients/clients, because older adults trust them as credible sources of health-related guidance.[64] However, many health care professionals, even exercise professionals, do not provide precise and individualized exercise advice to their older patients/clients for various reasons, including lack of training, lack of time, and not being adequately reimbursed for exercise counseling or referral.[64]

The ***F***requency, ***I***ntensity, ***T***ime, and ***T***ype, or the *FITT* principle of exercise prescription (Ex R_x) provides a structure by which health care and exercise professionals, especially physicians, can recommend exercise to their patients/clients for general health or specific health outcomes (e.g., lower blood pressure) in a systematic and individualized manner.[64,65] In addition, many resources exist to assist health care and exercise professionals in Ex R_x as will be shown later in this Chapter. Of these resources, the *American College of Sports Medicine's* (ACSM) *Guidelines for Exercise Testing and Prescription 10th Edition* (GETP10) are regarded as the golden standard.[65] Table 2 presents the key concepts of the FITT principle of Ex R_x for older adults.

[INSERT TABLE 2 HERE]

4.1 Exercise Pre-participation Health Screening for Older Adults

Overall, exercise is very safe for adults of all ages. The Physicians' and Nurses' Health Studies showed that the incidence of sudden cardiac death during exercise is extremely low, with 1 episode of sudden cardiac death/myocardial infraction for every 1.5 million episodes of vigorous physical exertion in men (mean age: ~53 years before 12-year follow-up),[66] and 1 episode of sudden cardiac death/myocardial infraction for every 36.5 million hours of moderate-to-vigorous exertion in women (mean age: ~53 years before 18-year follow-up).[67] However, vigorous intensity exercise increases the risks of sudden cardiac event, especially in people who are sedentary.[65] As a result, the first step in designing an Ex R_x is an exercise pre-participation health screening process.[65]

According to the ACSM exercise pre-participation health screening guidelines,[68] older adults seeking to begin an exercise program are first stratified by their physical activity level. Older adults are classified as “physically active” if they participate in planned, structured physical activity for at least 30 minutes on at least 3 days/week for at least 3 months.

When a *physically active* older adult: 1) does not have any cardiovascular, metabolic, or renal disease; and 2) does not have any signs and symptoms suggestive of cardiovascular, metabolic, or renal disease, such as dizziness or syncope (i.e., asymptomatic), she/he can continue with moderate to vigorous intensity (see Table 2) exercise programs, and gradually progress according to ACSM guidelines in ACSM GETP10.[65]

When a *physically active* older adult: 1) has cardiovascular, metabolic, or renal disease; and 2) is asymptomatic, she/he can continue with a low to moderate intensity exercise programs. Progression to vigorous intensity exercise requires medical clearance, and then the progression should follow the ACSM guidelines in ACSM GETP10 as tolerated.[65] An exception to this recommendation is when an older adult has been medically cleared in the past 12 months, and is still asymptomatic, she/he can participate in an exercise program of vigorous intensity.

When a *physically active* older adult is symptomatic, regardless of disease status, she/he should discontinue exercise of any intensity, and seek medical clearance. Only after she/he has been medically cleared, can that person restart exercise and gradually progress following ACSM guidelines in ACSM GETP10 as tolerated.[65]

When a *physically inactive* older adult: 1) does not have any cardiovascular, metabolic, or renal disease; and 2) is asymptomatic, she/he can start with light to moderate intensity exercise, and gradually progress following ACSM guidelines in ACSM GETP10 as tolerated.[65]

When a *physically inactive* older adult: 1) has cardiovascular, metabolic, or renal disease; and 2) is asymptomatic, she/he should start with low to moderate intensity exercise, and medical clearance is recommended. Progression should follow ACSM guidelines in ACSM GETP10 as tolerated.[65]

When a *physically inactive* older adult is symptomatic, regardless of disease status, she/he should start with low to moderate intensity exercise, and medical clearance is recommended. Progression should follow ACSM guidelines in ACSM GETP10 as tolerated.[65]

4.2 Clinical Exercise Testing Procedures and Considerations for Older Adults

According to the ACSM exercise pre-participation health screening guidelines,[68] most older adults will not require an clinical exercise test prior to initiating a light to moderate intensity exercise program.[65,69] However, if exercise testing is indicated, because older adults present with multiple chronic diseases and health conditions or are symptomatic, a physician or other health care and exercise professional should be overseeing the exercise test.[65] It should be noted that there is a lack of evidence that clinical exercise testing is effective in mitigating the risk of exercise-related cardiovascular events, so that general exercise testing recommendations prior to beginning an exercise program are no longer universally endorsed.[70] Rather, physicians are encouraged to evaluate the need for a medical examination, an exercise stress test, or diagnostic imaging using their own clinical judgment and on an individualized basis.[69] Therefore, only brief comment is made on the details of clinical exercise testing procedures in this Chapter.

When a treadmill stress test is used, the Modified Naughton Protocol is preferred for older adults because the initial workload is light (i.e., <3 metabolic equivalents [METs]) and the workload increments are small (i.e., 0.5-1.0 MET).[71] Meanwhile, a cycle ergometer stress test may be a better choice for older adults who have poor balance, poor neuromotor coordination, weight-bearing limitations, and/or orthopedic problems.[65] Regardless of the modality of stress test used, electrocardiograms have a higher sensitivity in older adults, and therefore a higher rate of false positive findings.[72] The criteria for test termination is similar for older adults and other age groups; however, due to the higher prevalence of cardiovascular, metabolic, and orthopedic problems in older adults, there is an increased likelihood of early test termination.[65] Lastly, health care and exercise professionals should also consider the impact that medications can have on an electrocardiogram and hemodynamic responses to exercise.[65,72] Table 3 presents examples of treadmill and cycle ergometer stress testing protocols.[73,74]

Of note, physical performance tests has become a more acceptable assessment of functional status of older adults than exercise stress tests.[75] The reasons for this change include physical performance tests: 1) cost less; 2) can be administered by personnel with minimum training; and 3) are safer than exercise stress tests.[76] Table 3 also presents examples of the most commonly used physical performance tests.[77-81] When performing physical performance tests, health care and exercise professionals should consider: 1) which specific population (e.g., community-dwelling older adults) is the test designed for; 2) the presence of floor or ceiling effects; and 3) the clinical meaning of change in scores.[65]

[INSERT TABLE 3 HERE]

4.3 The Exercise Prescription Recommendations for Healthy Older Adults

The ACSM recommends older adults should engage in a combination of aerobic, dynamic resistance, flexibility, and neuromotor exercise training (see Table 2 for the definition and examples of each type of exercise training) to promote and maintain health (see Table 4).[63,65] Of note, the ACSM guidelines apply not only adults who are 65 and older, but also individuals

50-64 years of age with clinically significant conditions or physical limitations that affect movement.[65] Although ACSM GETP10 is regarded as the gold standard in Ex R_x, we also include government endorsed exercise guidelines from four other professional committees/organizations, including: 1) the 2018 Physical Activity Guidelines Advisory Committee (PAGAC) from the US Department of Health and Human Services;[82] 2) the Canadian Society for Exercise Physiology (CSEP);[83] 3) the British Heart Foundation Centre (BHFC) for Physical Activity and Health;[84] and 4) the WHO.[13] It is beyond the scope of this Chapter to provide an exhaustive list of the exercise guidelines that exist for older adults, however, we highlighted guidelines that were: 1) drafted by a professional committee consisted of experts in the field of Ex R_x; 2) a systematic reviews of the literature; and 3) those funded/conducted by national-level health organizations. Similarities and differences contained within these exercise guidelines from five professional committees/organizations are summarized below.

- All five professional committees/organizations recommend aerobic exercise as the primary type of exercise that should be performed for at least 150 minutes/week at moderate intensity. They also recommend vigorous intensity aerobic exercise for older adults; however, the guidelines differ slightly in the time and frequency recommendations for vigorous intensity aerobic exercise. For example, ACSM recommends vigorous intensity aerobic exercise be performed 20-30 minutes/day on at least 3 days/week;[63,65] meanwhile, PAGAC,[82] BHFC,[84] and WHO recommend vigorous intensity aerobic exercise to be performed for at least 75 minutes/week.[13]
- All five professional committees/organizations recommend dynamic resistance exercise as an adjuvant type of exercise (i.e., in addition to aerobic exercise) that should be performed on at

least 2 days/week. However, only the ACSM and PAGAC recommend resistance exercise be performed at moderate to vigorous intensity. [63,65,82]

- Only the ACSM specifically recommends flexibility exercise as an adjuvant type exercise that be performed on at least 2 days/week.[63,65]Meanwhile, the BHFC states that flexibility exercise could be beneficial with no additional information;[84] and no other professional committees/organizations recommend flexibility exercise.
- All five professional committees/organizations recommend exercise that can improve balance be performed at least 2 days/week, as an adjuvant type of exercise for older adults who are at risk of falling or have poor mobility. The ACSM recommends neuromotor exercise,[8] which also targets coordination, gait agility, and proprioception in addition to balance.[65] In addition, there is no consensus on the frequency, intensity and time for neuromotor/balance exercise.

[INSERT TABLE 4 HERE]

4.4 Special Considerations in Exercise Prescription for Healthy Older Adults

There are numerous special considerations in Ex R_x for older adults, due to the physiological changes brought by primary aging and/or the presence of chronic diseases and health conditions. Special considerations for the healthy older adult population include:

- Exercise intensity and time should begin as light, especially for older adults who have impaired ability to perform physical tasks due to diseases/conditions such as arthritis.
- For older adults, especially those who have impaired physical function, progression should be individualized and tailored based on tolerance and preference. If chronic diseases and health conditions make it difficult to meet the exercise recommendations, patients should be encouraged to engage in any activity that is tolerable and avoid being sedentary. However,

older adults are encouraged to exceed the recommended minimum amount of exercise when willing and able to do so.[65]

- Muscular strength decreases rapidly with age; therefore, resistance exercise becomes important with increasing age.[65,85] Older adults may particularly benefit from high-velocity resistance exercise that targets muscle power. Individuals with sarcopenia (i.e., a degenerative loss of muscle mass, quality, strength and power associated with aging)[29] should increase muscular strength before engaging in aerobic exercise. Of note, experienced personnel should supervise the initial resistance exercise to ensure the corrected use of machines or free weight.[65]
- Health care and exercise professionals should incorporate behavioral strategies (e.g., social support, positive reinforcement) to maximize adherence with the Ex R_x.[65] Due to its importance, this topic is discussed in more detail later in this chapter.

4.5 Pharmacological Interactions with Exercise

The medications older adults are taking may have an impact on the recommended Ex R_x. US adults age 65 years and older account for 34% of all prescription medications and 30% of all over-the-counter medications.[86] Moreover, it is estimated that 80% of older adults >55 years use at least one prescription medication, and 30% use more than five prescription medications.[87-90] Older adults are more likely to experience adverse drug-related problems and side effects due to frailty, coexisting medical problems, memory issues, and the use of multiple prescribed and non-prescribed medications.[91] Therefore, it is crucial for health care and exercise professionals to consider the interaction between medication and exercise when designing Ex R_x for older adults.

Statin therapy is a common example of an interaction between a medication and exercise. Patients taking statins frequently experience muscle complaints including cramping, myalgia, soreness, and weakness which occur in approximately 5% to 10% of patients.[92] Older adults, along with high-performance athletes and individuals who are taking high-dose statins, have even higher muscle complaints.[93] These statin-related side effects may have a negative impact on exercise adherence among older adults. For example, Lee and colleagues followed 6000 older men (≥65 years) over 7 years,[94] and found that participants taking statins had a 10% decline in physical activity and displayed more sedentary behavior compared with controls. Older adults taking statins should be asked about muscle related complaints that occur following exercise and when present either the indication and or dose of statin should be reconsidered or their exercise recommendation may need to be adjusted.

5. Strategies to Increase Exercise Participation and Reduce Sedentary Behavior among Older Adults

Physical inactivity is very prevalent among older adults. In 2010,[60] about 90% of older adults ≥65 years, and over 95% of older adults ≥85 years, did not meet the aerobic and dynamic resistance exercise recommendations (see Table 4).[13,63,65,82-84] Therefore, it is important for health care and exercise professionals to unitize behavioral theories and strategies to promote exercise participation among older adults.

There are many behavioral theories to assist health care and exercise professionals when promoting exercise for their older patients/clients. For example, the Social Cognitive Theory states that behavioral changes in exercise (e.g., initiate and maintain swimming for 2 days/week) are the result of the interactions among personal factors (e.g., health status such as hip Osteoarthritis [OA]), behavioral factors (e.g., previous successful or failed experience with swimming), and environmental factors (e.g., availability of pools, and popularity of swimming in the society).[65,95] Of note, the interactions among personal, behavioral, and environmental factors are dynamic and change over time.[65,95] Meanwhile, the Transtheoretical Model identifies five stages of behavioral changes in exercise, including: 1) precontemplation (i.e., no intention to start swimming for 2 days/week in the next 6 months); 2) contemplation (i.e., intending to start swimming for 2 days/week in the next 6 months); 3) preparation (i.e., intending to start swimming for 2 days/week in the next 30 days); 4) action (i.e., swimming for 2 days/week for less than 6 months); and 5) maintenance (i.e., swimming for 2 days/week for longer than 6 months).[10,65] Of note, as older adults attempt to change their exercise behavior, they may go through these five steps linearly, or they may relapse and repeat certain steps several times.[10,65]

Evidence suggests that exercise interventions based on behavioral theory are effective in increasing exercise participation.[82] For example, Gourlan and colleagues meta-analyzed 39 theory-based interventions (e.g., interventions based on the Social Cognitive Theory or the Transtheoretical Model, or in combination) that measured exercise behavior directly (e.g., energy expenditure, time spent exercising, or number of steps taken) in middle-aged to older adults (mean age: 48.4 years), and found that theory-based interventions increased exercise participation with a moderate effect size of 0.31. Though these researchers did not observe any significant differences in exercise behavior as a result of the behavioral therapy used they did find that using one behavioral approach had stronger effects than using a combination of approaches (effect sizes: 0.35 vs. 0.21).[96] Based on this finding we will now focus on the Health Belief Model (HBM),[97] which is helpful when motivating individuals to exercise for specific health benefits,[65,98] and has been used frequently for the prevention and treatment of cardiovascular disease (CVD) and diabetes mellitus (DM).[99,100]

The HBM states that an individual’s beliefs about whether or not she/he is susceptible to a chronic disease or health condition, and his or her perceptions of the benefits of trying to avoid it, influence his or her readiness to act.[97] We will use a case study approach to illustrate the six key constructs in the HBM.

Case study*: Jason is a 68-year-old man with a body mass index (BMI) of 26.2 kg/m^2. During his last visit to his primary care physician (PCP), his blood pressure (BP) reading was 144/83 mmHg. He has limited mobility because of knee pain associated with OA. Jason lives with his wife, Cindy, who practices yoga 3 days/week. They have two dogs, though twice a day Cindy does most of the dog walking. Jason will walk when his knee pain is less, but he is generally very sedentary spending a lot of time sitting watching TV or reading. Jason's PCP who has cared for him for the past 6 years, who has recommended walking as his primary modality of aerobic exercise Unfortunately because of his progressive knee OA, Jason has been non-compliant with his walking program for the past 2 years. When he last met with his PCP, Jason discussed the recent increase in his BP and stated that he is not concerned about his BP at this point.*

The first key construct of the HBM is *perceived susceptbility*, which refers to an older individuals' beliefs about their susceptibility to chronic disease and/or acute changes in health.[97] In this case study, Jason's PCP might consider emphasizing Jason's high lifetime risk of developing hypertension.[101,102]

The second key construct of HBM is *perceived severity*, which refers to an older individuals' beliefs regarding whether a chronic disease or an acute change in health results in serious consequences.[97] In this case study, the PCP may consider educating Jason about the potentially serious consequences of poorly controlled hypertension.[103,104]

The third key construct of HBM is *perceived benefits*, which refers to older individuals' beliefs regarding whether exercise is effective in preventing or treating a chronic disease or acute change in health.[97] In this case study, the PCP may consider explaining to Jason the effectiveness of exercise in preventing and treating hypertension and point out that Jason can benefit immediately from even just 10 to 15 minutes of walking per day which has a blood pressure lowering effect that is similar to prescribing one BP medication.[105,106]

The fourth key construct of HBM is *perceived barriers*, which refers to older individuals' beliefs regarding potential drawbacks associated with exercise.[97] In this case study Jason's knee OA is a barrier that prevents his active participation in an exercise program. Therefore, the PCP might work with Jason on reducing the barrier that his knee OA produces by for example, advising Jason to wear a knee braces or foot orthotics while walking;[107] demonstrating a gait (e.g., toe-in gait) that can reduce joint stress;[107] explaining that the mild discomfort during and immediately after exercise is normal;[65] recommending that Jason should walk in short bouts (e.g., 15-minute bout);[108] and advising Jason to exercise when the level of pain is at the lowest during the day.[65] In addition, the PCP and Jason may explore other modalities of exercises that are low-impact (e.g., swimming, Tai Chi, yoga). Table 8 presents the common themes of barriers to exercise reported among older adults with examples of specific barriers for each theme. [109-115]

[INSERT TABLE 5 HERE]

The fifth key construct of HBM is *cue to action*, which refers to factors that initiate behavioral change.[97] For example, in this case study a further increase in his BP might induce Jason to start exercising.

The sixth key construct of HBM is *self-efficacy*, which refers to an older individuals' confidence in their capabilities to perform a task.[97] Self-efficacy is an important concept that is shared by many behavioral theories.[65,95,97] There are four sources of self-efficacy: 1) mastery experience; 2) vicarious experiences; 3) verbal persuasion; and 4) physiological feedback.[65,95]

Table 6 presents the definition of each source of self-efficacy, and provides examples of how to enhance self-efficacy from each source with cognitive and behavioral strategies.[65,95] In this case study, the PCP may consider working with Jason in several ways to enhance his self-efficacy in exercise, e.g. by setting realistic goals of walking for 45, 60, and 75 minutes for weeks 1, 2, and 3; advising Jason to record the time spent and the distance walked, asking Jason to record his physiological response to walking (i.e., pain levels of his knees before and after walking, and daily BP; recommending that Cindy encourage Jason and express her confidence in him to continuing to walk; and suggesting ways to make walking more enjoyable (e.g., join Cindy when she walks the dog, listen to music while walking, or join a walking group with other older adults who also have OA).

[INSERT TABLE 6 HERE]

Reducing sedentary behavior is important as emphasized in the 2018 PAGAC Scientific Report.[82] Sedentary behavior is defined as behavior (e.g., sitting, reclining) that has an energy expenditure ≤1.5 METs during waking hours. It is a separate construct from physical activity/exercise, since it is possible for an older adult to be physically active, but still spend the majority of his or her waking hours involved in sedentary activities, such as watching TV. Studies have identified a dose-response relationship between all-cause mortality and time spent in sedentary behavior.[82] For example, Biswas and colleagues meta-analyzed 14 cohort studies, and found that sedentary behavior increased all-cause mortality by 22%.[116] In addition, Chau and colleagues meta-analyzed six cohort studies, and found that sitting for more than 7 hours/day increased the all-cause mortality rate.[117] An older adults who sits more than 8 hours/day, needs to perform moderate intensity exercise 80 to 90 minutes/day to offset the associated increase in all-cause mortality from being that sedentary.[82,118] Older adults are at high risk for being sedentary with many older adults spending 65 to 80% of their waking hours in sedentary behavior,[119] and more than 70% of older adults spending $\geq$8.5 hours/day sitting.[120]

When attempting to reduce sedentary behavior for older adults, health care and exercise professionals should concentrate on a single behavioral intervention. Rosenberg and colleagues while investigating the effectiveness of an intervention based on the Social Cognitive Theory in 25 older adults (mean age: 71.4 years) found that an individualized approach worked best.[121]

Although the research on how to reduce sedentary behavior specifically among older adults is less established than similar research among children or office workers;[122-124] there are several promising strategies such as replacing sedentary behavior with light-intensity physical activity; and breaking up prolonged sitting with short periods of physical activity such as walking.[122,125]

Overall, there are few interventions as powerful as exercise for promoting healthy aging. Those who are younger now should remain active and exercise on a regular basis to promote good health when they are older and those who are older now should either continue exercising on a regular basis or begin an exercise program if they are primarily sedentary.

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Table 1. The Effects of Exercise on the Physiological Changes that Occur as a Result of Primary Aging among Healthy Older Adults.

Variables	Aging-Related Change	Impact Of Exercise*	Most Effective Exercise Modality
Cardiovascular Function[1-9]			
Resting heart rate	No change	Decrease	AET
Maximum heart rate	Decrease	Increase	AET
Maximum cardiac output	Decrease	Increase	AET
Ejection fraction	Decrease	Increase	AET
Absolute/relative O_2 uptake reserve	Decrease	Increase	AET
Lactate / ventilatory threshold	Decrease	Increase	AET
Submaximal work efficiency	Decrease	Increase	AET
Walking ability	Decrease	Increase or no change	AET/RET
Heart rate variability	Decrease	Increase	AET
Resting/Exercise blood pressure	Increase	Decrease	AET
Regional blood flow	Decrease	Increase	AET
Blood volume	Decrease	Increase	AET
Body fluid regulation	Decrease	Increase	AET
Muscular Function[10-21]			
Strength	Decrease	Increase or no change	RET
Power	Decrease	Increase or no change	RET
Endurance	Decrease	Increase or no change	RET/AET
Balance and mobility	Decrease	Increase or no change	NET/AET
Flexibility and range of motion	Decrease	Increase or no change	NET/FET
Pulmonary Function[11,15]			
Ventilation	Decrease	No change	AET
O_2 and CO_2 exchange	Decrease	No change	AET
Body Composition and Metabolism[22-24]			
Height	Decrease	No change	RET/NET
Weight	Decrease	No change	AET/RET
Fat-free mass	Decrease	Increase or no change	AET/RET
Muscle mass/size	Decrease	Increase or no change	RET
Muscle quality	Decrease	No change	RET
Visceral body fat	Increase	Decrease	AET/RET
Bone mass density	Decrease	No change	RET/AET
Metabolic rate	Decrease	Increase	AET/RET
Cognitive Function[25-29]			
Brain volume	Decrease	No change	AET/RET
Memory	Decrease	Increase or no change	AET
Executive functioning	Decrease	Increase or no change	AET/RET

Note. *These impacts can occur with the appropriate volume of exercise for each respective physiological variable. ***Abbr***: AET = aerobic exercise training; RET = resistance exercise training; NET = neuromuscular exercise training.

Table 2. Key Concepts of the *F*requency, *I*ntensity, *T*ime, and *T*ype (FITT) Principle of Exercise Prescription (Ex R_x)

***FITT* Components**	***FITT* Subcategories**	***FITT* Example or Definition**
Frequency (how often?)		How many days per week? For example, 3 days/week
Intensity (how hard?)	Light	A level of physical exertion that causes slight increases in HR and breathing, such as casually strolling in the mall or yoga practiced with inclusion of focused breathing techniques. *Examples of measurements:* Aerobic exercise: 39-39% VO_2R or HRR, 57-63% HR_{max}, 37-45% VO_{2max}, 9 to 11 on RPE Resistance exercise: 30-49% of 1-RM
	Moderate	A level of physical exertion that causes noticeable increases in HR and breathing, such as table tennis and brisk walking *Examples of measurements:* Aerobic exercise: 40-59% VO_2R or HRR, 64-76% HR_{max}, 46-63% VO_{2max}, 12 to 13 on RPE Resistance exercise: 50-69% of 1-RM
	Vigorous	A level of physical exertion that causes substantial increases in HR and breathing, as such swimming laps in the pool *Examples of measurements:* Aerobic exercise: 60-89% VO_2R or HRR, 77-95% HR_{max}, 64-90% VO_{2max}, 14 to 17 on RPE Resistance exercise: 70-84% of 1-RM
Time (how long?)		How many minutes per session? For example, 30 minutes/session
Volume (how much?)		The product of frequency, intensity, and time. For example, walking for 3 days/week at light intensity (e.g., 2.3 MET) for 30 minutes/session= 207 MET-minute/week

Type (what kind?)	*Aerobic exercise*, may also be referred as endurance exercise	Exercise that is intense enough and performed long enough for an individual to maintain or improve cardiorespiratory fitness, and commonly requires the use of large muscle groups. For example, walking, hiking, and swimming
	Resistance exercise (dynamic), may also be referred as strength, or muscle-strengthening exercise	Dynamic resistance exercise involves a type of muscle contraction during which the muscle generates force by changing length to move an object. Contractions that produce a lengthening of the muscle are termed eccentric, whereas those involving shortening are termed concentric. For example, lifting dumbbells and stretching therabands of different resistance.
	Flexibility exercise	Exercise that aims to increase range of motion. For example, static and dynamic stretching of hamstrings.
	Neuromotor exercise, may also be referred as functional fitness training	Exercise that incorporates various motor skills, including balance, coordination, gait, agility, and proprioceptive training. For example, yoga and Tai Chi.

Note. Abbr: FITT= frequency, intensity, time, type; VO_2R=oxygen uptake reserve; HRR= heart rate reserve; HR_{max} =maximal heart rate; VO_{2max}= maximal oxygen uptake; RPE=rating of perceived exertion; 1-RM=one repetition maximum; MET=metabolic equivalents.

Table 3. Examples of Treadmill and Cycle Ergometer Stress Tests and Physical Performance Tests for Older Adults

Modality	Protocol/Tests	Descriptions
Treadmill	Modified Naughton protocol[73]	An incremental exercise test on a treadmill with 2-minute stages and increments in both gradient and velocity simulating increments of about one metabolic equivalent.
Cycle Ergometer	YMCA submaximal protocol[76]	An incremental exercise test on a cycle ergometer with 3-minute stages and increments in power output. Each participant began exercising on a cycle ergometer at 25 watts on 50 rotations per minute. Power output progression was based on the participant's heart rate response to the first stage of exercise.
Physical Performance Testing	Senior Fitness Test[79]	Assesses upper and lower body strength, flexibility, agility, dynamic balance, and cardiorespiratory fitness. Includes chair stand, arm curls, up and go test, 6-minute walk, 2-minute step test, sit and reach, and back scratch.
	Short Physical Performance Battery[80]	Assesses lower extremity functioning and combines scores from usual gait speed and timed tests of balance and chair stands.
	Usual Gate Speed[81]	Assesses walking ability.
	6-minute Walk Test[82]	Widely used as an indicator of cardiorespiratory endurance.
	Continuous Scale Physical Performance Test[83]	Assesses the ability to perform activities of daily living (e.g., climbing stairs, carrying groceries) and is performed within an environmental context that represents underlying physical domains (e.g., carrying weighted a pot of water).

TABLE 4. Exercise Guidelines, Scientific Statements, and Recommendations for Older Adults[a] Made by Various Professional Committees and Organizations[b]

The FITT of the Ex R_x	Professional committee/organization		
	ACSM[65,67]	**PAGAC[84]**	**CSEP[85]**
***F*requency (How often?)**	If moderate intensity: ≥5 d/wk If vigorous intensity: ≥3 d/wk If combination of moderate and vigorous intensity: 3-5 d/wk	≥3 d/wk, spread throughout the week	None specified
***I*ntensity (How hard?)**	Moderate to vigorous[c]	Moderate to vigorous[c]	Moderate to vigorous[c]
***T*ime (How long?)**	30-60 min/d if moderate intensity 20-30 min/d if vigorous intensity[d,e]	If moderate intensity: ≥150 min/wk If vigorous intensity: ≥75 min/wk[e]	≥150 min/wk[d]
T*ype (What kind?) *Primary	Aerobic	Aerobic	Aerobic
Adjuvant 1	Resistance ≥2 d/wk Moderate to vigorous intensity[c] 8-10 exercise; 1-3 sets of 8-12 repetitions[f,g]	Muscle Strengthening ≥2 d/wk Moderate to high intensity 2-3 sets of 8-12 repetitions [f,g]	Muscle and Bone Strengthening ≥2 d/wk[f]
Adjuvant 2	Flexibility ≥2 d/wk Strength to the point of felling tightness or slight discomfort Hold strength for 30-60 sec		
Adjuvant 3	Neuromotor	Balance	Balance

	if at risk of falling 2-3 d/wk, 20-30 min/d	if at risk of falling ≥3 d/wk In addition, standardized balance exercises program	if mobility is poor

Note. Abbr. FITT= *F*requency, *I*ntensity, *T*ime, *T*ype, and *P*rogression of the exercise prescription; Ex R_x=exercise prescription; ACSM=American College of Sports Medicine; PAGAC=Physical Activity Guidelines Advisory Committee; CSEP=Canadian Society for Exercise Physiology; BHFC=British Heart Foundation Centre; WHO=World Health Organization.

[a] Older adults are referring to men and women age ≥ 65 yr and adults age 50 to 64 yr with clinically significant chronic conditions and/or functional limitations according to ACSM; Older adults are referring to men and women age ≥ 65 yr according to PAGAC, CSEP, BHFC; Older adults are refereeing to men and women age ≥ 60 yr according to WHO.

[b]Exercise guidelines from professional committees/organizations were selected if they were: 1) drafted by a professional committee consisted of experts in the field of Ex R_x; 2) a systematic review of the literature; and 3) funded/conducted by national-level health organizations.

[c] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

[d] Exercise can be performed in one continuous bout or multiple shorter bouts

[e] Exercise can be performed as an equivalent combination of moderate and vigorous intensity activity

[f] Resistance/muscle strengthening exercise should involve all the major muscle groups

[g] Appropriate progression is emphasized

TABLE 4 (continued). Exercise Guidelines, Scientific Statements, and Recommendations for Older Adults[a] Made by Various Professional Committees and Organizations[b]

The FITT of the Ex R_x	Professional committee/organization	
	BHFC[86]	**WHO[13]**
***F*requency** **(How often?)**	5 d/wk as example	None specified
***I*ntensity** **(How hard?)**	Moderate to vigorous[c]	Moderate to vigorous[c]
***T*ime** **(How long?)**	If moderate intensity: ≥150 min/wk If vigorous intensity: ≥75 min/wk[d,e]	If moderate intensity: ≥150 min/wk If vigorous intensity: ≥75 min/wk[d,e]
T*ype** **(What kind?)** ***Primary	Aerobic	Aerobic
Adjuvant 1	Muscle Strengthening ≥2 d/wk	Muscle Strengthening ≥2 d/wk[f]
Adjuvant 2	Flexibility Maybe beneficial	
Adjuvant 3	Balance if at increased risk of falling ≥2 d/wk	Balance if mobility is poor ≥3 d/wk

Note. Abbr. FITT= Frequency, Intensity, Time, Type, and Progression of the exercise prescription; Ex R_x=exercise prescription; ACSM=American College of Sports Medicine; PAGAC=Physical Activity Guidelines Advisory Committee; CSEP=Canadian Society for Exercise Physiology; BHFC=British Heart Foundation Centre; WHO=World Health Organization.

[a] Older adults are referring to men and women age ≥ 65 yr and adults age 50 to 64 yr with clinically significant chronic conditions and/or functional limitations according to ACSM; Older adults are referring to men and women age ≥ 65 yr according to PAGAC, CSEP, BHFC; Older adults are refereeing to men and women age ≥ 60 yr according to WHO.

[b]Exercise guidelines from professional committees/organizations were selected if they were: 1) drafted by a professional committee consisted of experts in the field of Ex R_x; 2) a systematic review of the literature; and 3) funded/conducted by national-level health organizations.

[c] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

[d] Exercise can be performed in one continuous bout or multiple shorter bouts

[e] Exercise can be performed as an equivalent combination of moderate and vigorous intensity activity

[f] Resistance/muscle strengthening exercise should involve all the major muscle groups

[g] Appropriate progression is emphasized

Table 5. Barriers to Exercise Participation among Older Adults: Common Themes and Examples

Common Themes	Description/Examples
Pre-existing Health Conditions	Having chronic disease or health conditions can be a barrier to exercise; especially when pain, or comorbidity is present.
Physical Environment	Neighborhood is not safe. Exercise facilities (e.g., gym, senior center, park) are far away. Public transportation is not available. This is especially limiting for older adults who live in long-term care facilities who do not have their own means of transportation.
Guidance from Health care and Exercise Professionals	Health care and exercise professionals do not offer enough advice on how to exercise. Lack of supervision from exercise professionals during exercise to ensure safety.
Beliefs about Exercise	Do not know how much exercise is enough/recommended. As a result, "I am already exercising enough" is a common belief. Think that exercise may lead to injury or result in falls, which will lead to the loss of independence. Do not know the health benefits of exercise.
Previous Experience with Exercise	Do not have any experience with exercise in childhood. Had negative experience with exercise, such as being forced to participate in sports during childhood.
Self-Efficacy	Do not believe that they have the ability to perform exercise.
Social Support/ Social Interaction	Cannot find people to exercise together with. Family members are concerned with safety issue, and discourage exercise. Individual is socially awkward, and is reluctant to participate in group exercise.

	Feel pressured to keep up with their peers, or people who are younger in group exercise.
Time Commitment	Do not have the time to exercise, due to reasons such as taking care of a sick partner. Do not want to spend time on exercise, due to other priorities such as spending time with grandchildren.
Affordability	Too expensive to hire a trainer. Limited exercise options that can be subsidized by insurance.

Table 6. Sources of Self-Efficacy and Cognitive and Behavioral Strategies to Enhance Self-Efficacy

Sources	Description	Examples of Cognitive and Behavioral Strategies
Mastery Experience	Have successful experience with participating in exercise	• Set precise, and quantifiable goals that can be reached; goals should be set primarily by the older adult. • The progression of exercise (e.g., time per exercise session, intensity) should be gradually increased over time. • Provide older adults with proper instruction and demonstration on how to perform specific exercise tasks. For example, teach older adults the gait that can reduce joint stress during walking. • Use exercise logs to track progress, such as an electronic physical activity tracker, or paper diary.
Vicarious Experience	Observe other older adults with similar background performing exercise	• Have appropriate group exercise leaders, who are experienced with communicating with older adults in group exercise settings, that older adults can identify with. • Provide videos of exercise tasks that older adults can follow. • Discuss “success” stories of individuals with similar background and characteristics. For example, an older adult who had great success managing knee osteoarthritis with Tai Chi exercise, and is now a Tai Chi instructor working with other older adults who also have osteoarthritis.

Verbal Persuasion	Have others tell the older adults that he/she can be successful in exercising	• Give frequent feedback and express confidence in the older adult's abilities to perform exercise.
Physiological Feedback	Communicate the meaning of symptoms associated with the exercise behavior change	• Provide appropriate instruction and reassurance. For example, instructions regarding feet care if the older adult has diabetic neuropathy in feet. • Provide education about the possible discomfort associated with exercise. For example, making the older adult aware that slight discomfort immediately after exercise is normal, but continuous monitoring should be adopted. • Discuss how exercise makes the individual feel. • Encourage using methods such as listing to music, exercising at a pleasant scenery to make exercise enjoyable.

Adapted from (65)

Chapter 2-B. Healthy Aging and Exercise: Treating Disease and Disability

Abstract: Exercise can be used to treat various chronic diseases and health conditions. This chapter first presents and summarizes the exercise prescription recommendations, following the frequency, intensity, time, and type principle, from international professional committees and organizations for five chronic diseases/health conditions. Second, through a case study approach, this chapter introduces an evidence-based decision support system to guide health care and exercise professionals to design an exercise prescription for individuals with multiple chronic diseases and health conditions.

Keywords: Alzheimer’s disease, evidence-based decision support system, exercise prescription recommendations, fall prevention, hypertension, older adults, osteoarthritis, type 2 diabetes

Table of Abbreviations:

Listed by the order of appearance in text

Ex R_x	Exercise prescription
T2DM	Type 2 diabetes mellitus
OA	Osteoarthritis
AD	Alzheimer's disease
BP	Blood pressure
CVD	Cardiovascular disease
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
JNC7	Seventh Report of the Joint National Committee
ACC	American College of Cardiology
AHA	American Heart Association
US	United States
RCT	Randomized controlled trial
CNCCD	Chinese National Center for Cardiovascular Disease
BSC	Brazilian Society of Cardiology
VO_{2max}	Maximum oxygen uptake
ACSM	American College of Sports Medicine
PEH	Postexercise hypotension
HIIT	High intensity interval training
VO_{2peak}	Peak oxygen uptake
CHEP	Canadian Hypertension Education Program
HR	Heart rate
DM	Diabetes mellitus
IDF	International Diabetes Federation
ADA	American Diabetes Association
CDA	Canadian Diabetes Association
ABCD	Association of British Clinical Diabetologists
DA	Diabetes Australia
CDS	Chinese Diabetes Society
BSD	Brazilian Society of Diabetes
HbA1c	Glycated hemoglobin
RPE	Ratings of perceived exertion
ACR	American College of Rheumatology
AAOS	American Academy of Orthopedic Surgeons
BMI	Body mass index
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
QoL	Quality of life
WHO	World Health Organization
FITT	Frequency, intensity, time, type
CDC	Centers for Disease Control and Prevention
LDL	Low density lipoprotein
CVH	Cardiovascular health

1. Exercise Prescription for a Single Chronic Disease or Health Condition

In this section, we will discuss the exercise prescription (Ex R_x) guidelines designed for a single chronic disease or health condition. We have selected hypertension, type 2 diabetes mellitus (T2DM), osteoarthritis (OA); and 4) Alzheimer's disease (AD). These four chronic diseases and health conditions were chosen due to their high prevalence among older adults, and their associated adverse health and social-economic consequences, which are detailed under each of these chronic diseases and health condition subheading below. In addition, at the end of this section, we will discuss the prevention of falls and fall related injuries.

1.1 Exercise Prescription for Hypertension

High blood pressure (BP) is the most prevalent and treatable cardiovascular disease (CVD) risk factor. Each 20-mmHg increment in systolic BP (SBP) and 10-mmHg increment in diastolic BP (DBP) increases and eventually doubles the risk of mortality from CVD;[1] Conversely, BP reductions of 5-10 mmHg lower the incidence of CVD by 20-40%.[1] According to the Seventh Report of the Joint National Committee (JNC7) criteria,[2] hypertension (SBP≥140 and/or DBP≥90 mmHg) affects approximately 1 billion (40.0%) adults ≥25 years of age worldwide and 86 million (34.0%) adults ≥18 years of age in the US.[3-5] In addition, hypertension results in about 9 million deaths globally and ~73,000 deaths annually in the US.[3,5]

Due to the significant public health burden of hypertension, the 2017 American College of Cardiology (ACC) and American Heart Association (AHA) Guidelines lowered the threshold of hypertension to ≥130 mmHg for SBP or ≥80 mmHg for DBP;[6] accordingly, 48% of all adults, and 75 to 85% of older adults (≥65 years) in the United States (US) now classified as having hypertension.[6] Of note, the 2017 ACC/AHA guidelines particularly emphasize the importance of lifestyle interventions to prevent, treat, and control hypertension, including regular exercise participation.[6] In this section we will follow the JNC7 definitions of hypertension (i.e., hypertension, prehypertension, and normal BP), because: 1) the majority of the research on exercise and hypertension has been conducted before the release of the 2017 ACC/AHA guidelines; and 2) researchers are still debating the clinical significance of the 2017 ACC/AHA guidelines in the US,[7] and its implications worldwide.[8-10]

The current consensus based on meta-analyses of randomized controlled trials (RCT) is that regular aerobic exercise and dynamic resistance exercise (i.e., resistance exercise that involves the type of contraction during which the muscle generates force by changing length to move an object;[11] such as arm curls) performed separately or in combination, lowers BP by 5 to 8 mmHg among individuals with hypertension.[6,12] Consistent with the law of initial values,[13,14] the greatest BP reductions should occur in those with the highest resting BP, which would be those with hypertension compared to those with normal BP or prehypertension. Therefore, it is important to note that the antihypertensive effects of exercise are likely to be underestimated in many studies due to the inclusion of subjects with hypertension and those with normal BP and prehypertension as well.[14,15]

In 2015, Pescatello and colleagues reviewed the exercise recommendations for hypertension from six professional committees/organizations,[16] including the European Society of Hypertension.[17] In this chapter, we have updated this review have replaced the older AHA guidelines with the 2017 ACC/AHA guidelines;[6] and include recommendations from the Chinese National Center for Cardiovascular Disease (CNCCD),[18] and the Brazilian Society of Cardiology (BSC).[19] Please see Table 1 for details. In synthesizing exercise recommendations from the seven professional committees/organizations, the following conclusions can be made:

[INSERT TABLE 1 HERE]

Frequency:

Six out of the seven professional committees/organizations recommend a high frequency of exercise (i.e., ranging from 4 to 7 days/week) for individuals with hypertension. The American College of Sports Medicine (ACSM) and CNCCD even state that exercising every day is preferred.[12,18] Meanwhile, the 2017 ACC/AHA guidelines do not specify the frequency of exercise (see Table 5).[6] This frequency recommendation evolved from the findings that after a single bout of aerobic exercise of varying length (10 to 50 minutes) and intensity (40% to 100% of maximum oxygen uptake [VO_{2max}]), BP is immediately lowered 5 to 7 mmHg for up to 24 hours.[12,20-22] This well-established BP response to a single bout of exercise has been termed *postexercise hypotension* (PEH).[23] PEH lowers BP on days when older adults exercise more than on days they do not exercise. Evidence has shown that older adults enjoy exercise routines if they experience acute/immediate health benefits.[24] Health care and exercise professionals should make older adults aware of the immediate PEH that can result from a small amount of walking and point out that exercise lowers BP during the day when BP is typically at its highest.[11,25]

Intensity:

Five out of the seven professional committees/organizations recommend moderate intensity exercise. Meanwhile, the 2017 ACC/AHA guidelines recommend vigorous intensity exercise,[6] and JNC7 does not specify the intensity of exercise (see Table 1).[2] Of note, there is a dose-response relationship between exercise intensity and the magnitude of the BP reductions that result from exercise.[26-29] Eicher and colleagues investigated the acute BP response to one bout of 30-minute cycle exercise at light intensity (i.e., 40% VO_{2max}), moderate intensity (i.e., 60% VO_{2max}), and vigorous intensity (i.e., 100% VO_{2max}), and observed average SBP/DBP was reduced by ~3/2 mmHg, ~5/2 mmHg, and ~12/5 mmHg, respectively.[27] Thus, if an older adult is willing and able, they will experience greater reduction in BP from more rigorous levels of physical exertion.

Older adults can also perform short periods of vigorous intensity exercise, interspersed by short periods of light intensity exercise or simply resting. This is termed high intensity interval training (HIIT), and ensuing BP reductions are similar to those that result from longer durations of moderate intensity exercise, while also reducing the time of each exercise session. For example, Nemoto and colleagues compared a HIIT training program (i.e., five sets of 3-minute walking at 70% to <85% peak oxygen uptake [VO_{2peak}] followed by a 3-minute walking at 40% VO_{2peak}) to a continuous walking training program (i.e., ~60 minutes of walking at ~50% of VO_{2peak} continuously) among 246 older adults (mean age: 63 years),[30] and found that the HIIT training program reduced BP more than the continuous walking training program (SBP/DBP, ~9/5 mmHg vs. ~3/2 mmHg, respectively) after 5 months.

Of note, even though vigorous intensity exercise results in larger BP reductions than moderate intensity exercise, moderate intensity is still recommended by most professional committees/organizations who feel that performing moderate intensity exercise optimizes the benefit-to-risk ratio in that it reduces the risk of an acute cardiac event and musculoskeletal injuries compared to more rigorous levels of physical exertion.[25]

Time:

Six out of the seven professional committees/organizations recommend that older adults with hypertension should exercise for 30 to 60 minutes/day accumulating to at least 150 minutes/week. Meanwhile, the 2017 ACC/AHA guidelines recommend 90-150 minutes/week, with no information provided on daily time (see Table 1).[6] Studies consistently show that shorter and longer bouts of exercise can both elicit PEH. For example, Guidry and colleagues found that, among 45 middle-aged men, a single bout of light to moderate intensity exercise (40% to 60% VO_{2max}) performed for as short as 15 minutes resulted in SBP/DBP reductions up to ~6/2 mmHg for the rest of the day. This was not significantly different from one bout of exercise at similar intensity performed for 30 minutes continuously which resulted in SBP/DBP reductions up to ~5/4 mmHg.[31] In addition, training studies also show that shorter bouts of aerobic exercise which accumulate to the same time of a longer bout of aerobic exercise, lowers BP to similar degree. For example, Jakicic and colleagues compared the BP responses to a fractionated exercise training program (i.e., two to four 10-minute exercise bouts per day for 5 days/week) to a continuous exercise training program (i.e., 20 to 40 minutes of continuous exercise per day for 5 days/week), both performed at moderate intensity, among 56 middle-aged women (mean age: ~41 years).[32] They found that the two exercise training programs resulted in BP reductions of similar magnitude (i.e., SBP/DBP, ~3/5 vs. ~4/4 mmHg, respectively) after 20 weeks.[32]

Therefore, the magnitude of the BP reductions that result from acute (i.e., PEH) and chronic (i.e., training effect) aerobic exercise appear to be independent of the length of the exercise sessions as long as the total time spent exercising is similar.[11] This finding is encouraging for older adults who have physical limitations and find it difficult to exercise for longer periods of time. As an alternative they can perform multiple short bouts of aerobic exercise in the morning, afternoon, and evening which tighter add up to 30 minutes of exercise per day, and meet the current time recommendations to treat, and control hypertension.

Type:

Five out of the seven professional committees/organizations recommend that older adults with hypertension should perform aerobic exercise as the primary type of exercise, and supplement their aerobic exercise training program with dynamic resistance exercise.

Meanwhile, the 2017 ACC/AHA guidelines and the Canadian Hypertension Education Program (CHEP) recommendations also endorse the use of isometric resistance exercise (i.e., resistance exercise that involves the type of muscle contraction during which the muscle generates force without lengthening and movement of the object;[11] such as isometric handgrip).[6,33] JNC7 and CNCCD do not recommend any adjuvant type of exercise in addition to aerobic exercise (see Table 1).[2,18]

There is strong evidence demonstrating the antihypertensive effects of aerobic exercise. For example, Cornelissen and Smart meta-analyzed 93 exercise trials and found that aerobic exercise performed, on average, at moderate- to-vigorous intensity for 40 minutes/session, 3 days/week, for 16 weeks elicited SBP/DBP reductions of ~4/3 mmHg; and the greatest SBP/DBP reductions occurred among samples with hypertension (~8/5 mmHg), followed by samples with prehypertension (~4/2 mmHg) and samples with normal BP (~1/1 mmHg).[26] There is also a convergence of evidence supporting the efficacy of using dynamic resistance exercise and combined exercise (i.e., aerobic and dynamic resistance exercise being performed in proximity to each other, in the same session or on separate days, also referred to as concurrent exercise) for the treatment of hypertension. MacDonald and colleagues meta-analyzed 64 exercise training studies and found that dynamic resistance exercise performed, on average, at moderate intensity for 32 minutes/session, 3 days/week, for 15 weeks elicited SBP/DBP reductions of ~3/2 mmHg; and here again the greatest SBP/DBP reductions occurred among samples with hypertension (~6/5 mmHg), followed by samples with prehypertension (~3/3 mmHg) and samples with normal BP (~1/0 mmHg).[34] Meanwhile, Corso and colleagues meta-analyzed 68 exercise training studies and found that concurrent exercise performed, on average, at moderate intensity for 58 minutes/session, 3 days/week, for 20 weeks, elicited SBP/DBP reductions of ~2/3 mmHg;

and once again the greatest SBP/DBP reductions occurred among samples with hypertension (~5/6 mmHg), followed by samples with prehypertension (~3/4 mmHg), and samples with normal BP (~1 mmHg increase/1.5 mmHg).[35] Therefore, it now appears that the type of exercise among older adults does not have a significant impact on the resulting magnitude of BP reduction, regardless of whether the person has normal BP or hypertension.[11]

The Ex R_x recommendations for adults with hypertension are summarized in Table 4. Here are the additional special considerations:

- Taking multiple BP medications increases the risk of excessive reductions in BP after exercise; therefore, older adults should avoid sudden termination of exercise. In a supervised exercise setting, health care and exercise professionals may consider adding an extended cool down period, and monitoring older adults' BP and heart rate (HR) until they return to approximately resting levels.
- If older an adult's resting SBP exceeds 200 mmHg or DBP exceeds 110 mmHg, before exercise, she/he should postpone exercise until the BP is lower. During a supervised exercise session, health care and exercise professionals should periodically measure BP to ensure SBP remains less than 220 mmHg and DBP remains less than 105 mmHg.
- Inhaling and breath holding while lifting a weight (i.e., Valsalva maneuver) can result in extremely high BP responses, dizziness, and even fainting. Thus, this practice should be avoided by older patients with hypertension, during resistance exercise.
- Beta-blockers and diuretics, types of medication which are used to treat hypertension, may adversely affect exercising in the heat or increase the predisposition to hypoglycemia in certain individuals.[25] Therefore, appropriate precautions should be taken in these situations. In addition, individuals taking beta-blockers and diuretics should be well informed about

signs and symptoms of heat intolerance and hypoglycemia, and should be educated on how to make necessary modifications in their exercise routines to prevent adverse events.[25]

1.2 Exercise Prescription for Type 2 Diabetes Mellitus

Currently, there are 326.5 million adults aged 20-64 years living with diabetes mellitus (DM), and 122.8 million adults aged ≥65 years living with DM.[36] Furthermore, among these two age groups, the number of individuals living with DM is expected to increase to 438.2 million (34.2% increase), and 253.4 million (100.6% increase) by 2045.[36] Health expenditure for DM will increase by ~$230 billion US dollars from 2015 to 2040.[36,37] About 90% of adults living with DM have T2DM.[38] Though T2DM is partially hereditary an unhealthy diet and physical inactivity are important drivers of the current global epidemic.[38]

The International Diabetes Federation (IDF) is an umbrella organization of over 230 national diabetes associations. In the document named *Global Guidelines for Type 2 Diabetes*,[39] the IDF recommends regular exercise participation for older adults with T2DM based on the exercise recommendations from the following four professional committees/organizations: 1) the American Diabetes Association (ADA); 2) the Canadian Diabetes Association (CDA); 3) the Association of British Clinical Diabetologists (ABCD); and 4) the Diabetes Australia (DA). In this chapter, we updated the IDF guidelines to include the most recent exercise recommendations from ADA,[40] CDA,[41] and DA,[42] while there is no newer version of the ABCD receommendations.[43] In addition, we added the exercise recommendations from the: 1) ACSM;[44] 2) Chinese Diabetes Society (CDS);[45] and 3) Brazilian Society of Diabetes (BSD).[46] Please see Table 2 for details. Based on exercise recommendations from these seven professional committees/organizations, the following conclusions can be made:

[INSERT TABLE 2 HERE]

Frequency:

Four out of the seven professional committees/organizations recommend that older adults with T2DM exercise 3 to 7 days/week. Of these, ADA, DA, and CDS state that individuals with T2DM should not spend more than two consecutive days without exercise.[40,42,45] Meanwhile, CDA recommends that older adults with T2DM exercise on 4 to 5 days/week;[41] BSD and ABCD do not specify a frequency.[46,43] These frequency recommendations evolved from the findings that after a single bout of exercise, from prolonged light intensity aerobic exercise (≥ 60 minutes) to short vigorous intensity aerobic exercise (≥ 20 minutes), insulin activity can be improved for 12 to 48 hours.[47] For example, Manders and colleagues compared the effects of a single bout of light intensity aerobic exercise to a non-exercising control on insulin activity among nine older male patients (mean age: 57 years).[48] They found that exercise significantly reduced: 1) 24-hour glucose levels compared to control (7.8 mmol/L vs. 9.4 mmol/L, respectively); and 2) the time spent in a hyperglycemia state for 24 hours following exercise was reduced by 50% compared to control.[48] Patients with DM should exercise on 3 to 7 days/week.

Intensity:

All seven professional committees/organizations recommend that individuals with T2DM should perform moderate to vigorous intensity aerobic exercise. In addition, the ADA, CDS, and ACSM also recommends that individuals with T2DM perform moderate to vigorous intensity dynamic resistance exercise. [40,45,44] The remainder of the four professional committees/organizations do not specify the intensity of dynamic resistance exercise. Similar to BP, there is a dose-response relationship between exercise intensity and insulin activity following exercise. For example, Liubaoerjijin and colleagues meta-analyzed eight exercise training studies that directly compared the glycated hemoglobin (HbA1c) concentration change resulting from aerobic exercise at different intensities, and found that higher-intensity exercise resulted in an additional 0.22% (% is the standard unit of HbA1c) reduction in HbA1c compared to lower-intensity exercise.[49]

Older adults can also perform a HIIT program to improve insulin activity, while reducing the duration of each exercise session. For example, Karstoff and colleagues compared the change in glucose levels after a HIIT program (i.e., repetitions of 3-minute walking at above 70% VO_{2peak} plus 3-minute of walking at below 70% VO_{2peak}), a continuous-walking training program (i.e., continuous walking at 55% of VO_{2peak}), and non-exercise control among 36 older adults (mean age: 60.8 years).[50] Both exercise training programs were performed 5 days/week, 60 minutes/day for 16 weeks, and were matched on total energy expenditure. The authors found that glucose levels: 1) increased from baseline to 4-month in the control group (i.e., 7.1 vs. 8.3 mmol/L); 2) remained similar after the continuous-walking training program (8.0 vs. 8.1 mmol/L); and 3) decreased after the HIIT program (8.2 vs. 7.5 mmol/L).[50]

Time:

Five out of the seven professional committees/organizations recommend that older adults with T2DM exercise at moderate,[40,46,41] or moderate to vigorous intensity,[43,44] for at least 150 minutes/week. Meanwhile, the DA recommends at least 210 minutes/week of moderate intensity exercise,[42] and the CDS recommends 30 minutes/day of moderate intensity exercise with no specification on time per week.[45] In addition, ADA and DA state that older adults with T2DM can also exercise at vigorous intensity for at least 75 minutes/week,[40] or at vigorous intensity for at least 125 minutes/week,[42] respectively. The total time of weekly exercise is associated with an improvement in insulin sensitivity and glycemic control which is independent of individual exercise time and intensity.[40] Umpierre and colleagues meta-analyzed 47 exercise training studies and found that the overall duration of exercise, elicited reductions in HbA1c concentration by 0.67% compared with controls. In addition, independent of time per exercise session and exercise intensity, exercise interventions of more than 150 minutes/week elicited greater HbA1c reductions than exercise interventions of 150 minutes/week or less (-0.89% vs. -0.36%;).[51]

Type:

All seven professional committees/organizations recommend that older adults with T2DM perform aerobic exercise supplemented by dynamic resistance exercise. Meanwhile, the ADA and ACSM also recommend flexibility exercise,[40,44] and only the ADA recommends balance exercise for older adults with T2DM.[40] Studies have shown that both aerobic and dynamic resistance exercise result in comparable insulin action improvement.[40] Umpierre also[51] found that both aerobic exercise alone and dynamic resistance exercise alone resulted in similar HbA1c reductions from (−0.73% vs. −0.57%; % is the unit of HbA1c).[51] There is merging evidence which shows that combined aerobic and resistance exercise (i.e., concurrent exercise) is more effective in improving insulin action than either aerobic or resistance exercise alone. For example, Sigal and colleagues compared the HbA1c responses to different types of exercise training (i.e., 3 sessions/week for 22 weeks) among 251 middle-aged to older adults with T2DM (mean age: 58.4 years).[52] They found that combined exercise training elicited an additional 0.46% reduction in HbA1c compared with aerobic exercise alone, and an additional 0.59% reduction in HbA1c compared with dynamic resistance exercise alone.[52]

Although there is insufficient evidence to support the use of flexibility and neuromotor exercise for the treatment of T2DM,[53,54,55,56] because neuropathic changes are common in older adults with T2DM, these are still recommended.[57,58]

The Ex R_x recommendations for adults with T2DM are summarized in Table 4. Here are the additional special considerations:

There are many special considerations for older adults with T2DM. The most serious problem is hypoglycemia, defined as blood glucose level <70 mg/dL.[40] In addition, unlike younger adults, older adults with T2DM lack the ability to increase the production of glucose in the liver during fasting, which results in an increased the risk of hypoglycemia.[40] Therefore, older adults with T2DM should:[25,44,59]

- Avoid more than two consecutive days without exercising
- Gradually increase the intensity of dynamic resistance exercise due to joint mobility limitations
- Monitor blood glucose before exercise; exercise should be supervised if hypoglycemia is present before exercise
- Monitor blood glucose during exercise, and be aware the signs and symptoms related to hypoglycemia, such as shakiness, weakness, abnormal sweating, mental dullness, or even amnesia and seizures
- Monitor blood glucose before and after exercise, and adjust carbohydrate intake before and after exercise and the medication regimen accordingly to maintain normal blood glucose levels, in consultation with health care and exercise professionals
- Use continuous glucose monitors to record glucose levels continuously to detect patterns across multiple days and to evaluate the immediate and delayed effects of exercise
- Exercise with a partner or under supervision if there is a history of exercise induced hypoglycemia; in addition, carry medical ID identifying diabetes, a cell phone, and a form of rapid carbohydrate treatment for hypoglycemia (e.g., glucose tablets)

- Avoid exercise that will dramatically increase BP in the presence of diabetic retinopathy to prevent vitreous hemorrhage
- Adopt proper care of feet (e.g., keep the feet dry, examine the feet closely daily to detect and treat scores and ulcers early) in the presence of periphery neuropathy to prevent foot ulcers and lower the risk of amputation
- Monitor the following in the presence of autonomic neuropathy: 1) the signs and symptoms of silent ischemia (e.g., unusual shortness of breath and back pain); 2) BP before and after exercise to manage hypotension and hypertension; and 3) exercise intensity with ratings of perceived exertion (RPE) because the BP and HR response to exercise may be blunted

1.3 Exercise Prescription for Osteoarthritis

OA is characterized by the degeneration of articular cartilage in synovial joints,[60] attributed to changes outside the joints (e.g., sarcopenia, impaired proprioception) and within the joints (e.g., cell and matrix changes in joint tissues).[61] There is no consensus regarding the prevalence of OA because reported numbers vary greatly from epidemiology studies based on gender, age, diagnose methods, and affected joint regions.[62] Studies have reported an age-standardized prevalence of hip OA up to 19.6%,[63] and knee OA up to 25.4% among adults aged 56 to 84 years;[64] and that ~50% of adults have OA in at least one of four joint regions (i.e., hand, hip, knee, foot).[65] OA is the leading cause of pain and disability among adults,[62] with pain and disability occurring in 40% of older adults aged ≥65 years due to OA of the knee and hip.[66-68] OA is an irreversible condition so that OA management is focused on controlling pain and reducing physical disability and handicap.[60]

Evidence indicates that exercise benefits individuals with hip and knee OA through the strengthening of muscles that help stabilize of joints affected by OA, improving proprioceptive accuracy, and reducing excessive pressure on joints through weight loss.[60] Following the US Bone and Joint Initiative, Nelson and colleagues conducted a systematic review of the guidelines for the management of OA from 15 professional committees/organizations;[69] among which, six specifically recommend exercise for the management of OA. In this section we included exercise recommendations from these six professional committees/organizations, including: 1) the Ottawa Methods Group from Canada;[70] 2) the American College of Rheumatology (ACR);[71] 3) The American Academy of Orthopaedic Surgeons (AAOS);[72] 4) the MOVE consensus committee from the United Kingdom;[73] 5) the National Collaborating Centre on Chronic Conditions from the United Kingdom;[74] and 6) the OARSI panel with experts from the US, United Kingdom, France, Netherlands, Sweden and Canada.[75] In addition, we included exercise recommendations from the ACSM.[25] Please see Table 3 for details. In synthesizing exercise recommendations from these seven professional committees/organizations, the following conclusions can be made:

[INSERT TABLE 3 HERE]

Frequency:

Six out of the seven professional committees/organizations do not provide information regarding the frequency of exercise; meanwhile, the ACSM recommends that older adults with OA follow the Ex R_x for healthy older adults when willing and able and that older adults with OA should perform aerobic exercise 3 to 5 days/week, dynamic resistance exercise 2 to 3 days/week, and flexibility exercise 7 days/week.[25] Of note, being overweight or obese is the most important modifiable risk factor of OA,[76] and exercising 3 to 5 days/week combined with diet, is more effective in reducing weight and managing OA symptoms than diet alone. For example, Messier and colleagues compared combined aerobic and dynamic resistance exercise training (i.e., 60 minutes/day for 3 days/week) plus a calorie restricted diet of 1100-1200 Kcal/day compared to diet alone among older adults with OA who were obese (mean age: 66 years; body mass index [BMI]=33.6 kg/m^2).[76] After 18 months, compared to diet alone, the addition of an aerobic and dynamic resistance exercise resulted in: 1) more weight loss (10.6 kg vs. 8.9 Kg, respectively); 2) lower levels of pain (3.6 points vs. 4.7 points on the Western Ontario and McMaster Universities Osteoarthritis Index [WOMAC] pain scale, respectively); and 3) higher levels of physical function (14.1 vs. 17.4 points on the WOMAC function scale, respectively).[76]

Intensity:

Six out of the seven professional committees/organizations do not provide information regarding the intensity of exercise; meanwhile, the ACSM recommends that older adults to follow the Ex R_x for healthy older adults when willing and able and that older adults with OA should exercise at moderate to vigorous intensity.[25] Of note, as first discussed in Ex R_x for hypertension, moderate intensity optimizes the benefit-to-risk ratio in that it reduces the risk of an acute cardiac event and musculoskeletal injuries compared to more rigorous levels of physical exertion.[25] In addition, Regnaux and colleagues meta-analyzed six exercise training studies that directly compared high versus low intensity exercise in OA management.[77] On average, exercise was performed for 30 minutes/day, 3 days/week for 24 week. Results from this meta-analysis showed that high intensity exercise resulted in an additional 4% reduction in pain level, an additional 4% improvement in physical function, and an additional 2% improvement of quality of life (QoL) compared to low intensity exercise However, these authors stated that these small additional benefits from performing high intensity exercise may not be clinically meaningful.[77] Meanwhile, adverse effects (e.g., pain, fatigue) were more commonly reported among individuals who performed high intensity exercise than low intensity exercise (3.9% versus 2.2%); although the difference was not statistically significant.[77]

Time:

Six out of the seven professional committees/organizations do not provide information regarding the time of exercise; meanwhile, the ACSM recommends that older adults with OA follow the Ex R_x for healthy older adults when willing and able and that older adults with OA should exercise for at least 30 minutes/day, accumulating to ≥150 minutes/week at moderate intensity.[25] Farrokhi and colleagues compared continuous (i.e., at 1.3 meters/second for 45 minutes) and interval (i.e., at 1.3 meters/second for three 15-minute bouts with 60-minute resting period in between) walking among 27 older adults with knee OA.[78] They found that although 30-minutes of walking (continuously or in two separate bouts) peaked the contact force at knee joints, only continuous walking resulted in an increase in acute knee pain.[78]

Type:

All seven professional committees/organizations recommend aerobic and dynamic resistance exercise for the management of OA. The Ottawa Methods Group, ACR, and AAOS recommends neuromotor exercise for the management of OA;[70,71,72] though the ACR states that evidence is still inconclusive regarding the type of exercise that should be done.[71] The Ottawa Methods Group, ACR, and the OARSI endorse the use of aquatic exercise for the management of OA;[70,71,75] though the Ottawa Methods Group states that here to, evidence is still inconclusive.[70] The OASRI states that aquatic exercise is only recommended when OA symptoms (e.g., swelling, pain) are present.[75] Surprisingly, only the OARSI and ACSM specifically support the use of flexibility exercise for the management of OA.[75,25]

Evidence indicates that aerobic and dynamic resistance exercise training programs can relieve pain, alleviate OA symptoms, and improve physical function among older adults with OA.[11] For example, Juhl and colleagues meta-analyzed 48 exercise training studies among older adults with OA (mean age: 64.3 years),[79] and found similar pain relief benefits from aerobic and dynamic resistance exercise training programs (effect sizes: 0.67 vs. 0.62, p= 0.733).[79] In addition, studies have shown that aquatic and land-based exercise training programs can result in similar benefits for the management of OA. For example, Batterham and colleagues meta-analyzed 10 RCTs that directly compared aquatic and land-based exercise training programs.[80] They found that compared to land-based exercise training programs, aquatic exercise training programs did not result in additional improvement (ps>0.05) in physical function (effect size: 0.07), mobility (effect size: 0.04), or balance (effect size: 0.16).[80] However for some patients aquatic exercise can offer the unique benefit of immediate pain relieve because: 1) water offers buoyancy that can reduce joint stress during exercise; and 2) a heated pool may aid in muscle relaxation, and reduce pain.[70,75]

Of note, all seven professional committees/organizations have emphasized that older adults with OA should select exercise modalities that provide low joint stress such as walking or swimming. For example, Dore and colleagues followed 405 adults (age: 51 to 81 years) for three years to examine the relationship between knee structural damage (e.g., bone marrow lesions, cartilage defects) and level of physical activity. They found that individuals can safely accumulate 10,000 steps/day without increasing the risk of damage to the knee.[81] In addition, even for individuals who have troubles with walking due to OA, new technologies are being developed to reduce joint stress during walking. For example, Peeler and colleagues evaluated the effect of lower body positive pressure technology during treadmill walking among 31 older adults with mild to moderate knee OA with overweight or obesity (mean age: 64 years; average BMI: 32.8 Kg/m^2). They found treadmill walking (i.e., at the speed of 3.1 mph for 30 minutes/session, 2 days/week) with the positive pressure technology reduced joint stress significantly, alleviated knee joint symptoms (17% improvement), improved physical function (22% improvement), increased thigh muscle strength (16-29% improvement), reduced acute knee pain during full weight walking (50% improvement), improved ability to perform ADL (14% improvement), and improved QoL (44% improvement) after 12 weeks.[82]

There is evidence to support the use of neuromotor exercise for the management of OA. For example, Zhang and colleagues meta-analyzed eight Tai Chi exercise training programs among older adults with OA, and found that Tai Chi reduced pain, improved physical function, and alleviated joint stiffness.[83]

The Ex R_x recommendations for adults with OA are summarized in Table 4. Here are the additional special considerations:

- During acute flare-ups of OA, older adults should avoid strenuous exercise
- Older adults with OA should exercise at the time of the day when they are experiencing the lowest level of pain; for example, right after taking pain medication
- Health care and exercise professionals may consider making older adults with OA aware that a low level of discomfort in muscles and joints are normal during or immediately after exercise. However, the pain level should be monitored again in 2 hours following an exercise session, if the pain level is higher at 2 hours after exercise compared to before exercise, time and intensity should be reduced in the next exercise session
- In land-based exercise, older adults with OA should wear appropriate foot wear that provides shock adsorption and stability. During aquatic exercise, the water temperature should be 83 to 88°F for the best pain relief effects

1.4 Exercise Prescription for Alzheimer's Disease

Dementia is the 7th leading cause of death worldwide. Currently, there are about 50 million people living with dementia worldwide; this number is projected to increase to 82 million by 2030 and 152 million by 2050 largely due to the aging of the population.[84] The global cost of dementia care was estimated to be $818 billion US dollars in 2015.[84] The most prevalent type of dementia is AD, accounting for ~70% of all dementia cases,[84,85] which can cause from mild to great memory loss and the loss of functional independence, and various behavioral change.[86,87,88]

There are currently no evidence-based Ex R_x guidelines specifically for individuals with AD. However. However the World Health Organization (WHO),[89] the US National Institute on Aging,[90] the British Alzheimer's Society,[91] and the Alzheimer Society of Canada[92] all emphasize that it is important for older adults with AD to stay physically active, and follow the Ex R_x guidelines for healthy older adults when willing and able.

Frequency

According to the WHO and other professional committees/organizations (Table 3), older adults should exercise at least 3 to 5 days/week.[93,25,94,11,95,96] This recommendation is supported by research among older adults with AD that investigated the cognitive benefits of exercise. For example, in a recent meta-analysis, Panza and colleagues meta-analyzed 19 exercise training trials among older adults (mean age: 77.0 years) who were at risk of or diagnosed with AD, and found that over the course of ~19 weeks, the non-exercise control group demonstrated a significant decline in cognitive function; while the group that performed moderate intensity exercise (i.e., aerobic exercise alone or combined with dynamic resistance exercise) for 3.4±1.4 days/week had significant improvements in cognitive function. As a result, moderate intensity exercise performed 3 to 4 days a week showed moderate positive effects on cognitive function compared to control.[97]

Studies have also demonstrated that exercise can improve cognitive functions such as executive function, processing speed, attention, and memory shortly after the completion of the exercise activity.[11] For example, Chang and colleagues meta-analyzed 79 exercise studies to investigate the short-term cognitive benefits of exercise among participants of all ages and found that single bout of exercise elicited transient but significant cognitive benefits.[98] These authors found that only exercise performed in the morning provided significant short-term cognitive benefits while exercise performed in the afternoon, evening or at mixed time points during the day, did not.[98]

Intensity

Because cardiorespiratory and musculoskeletal fitness is impaired as AD progresses, older adults with AD, should begin exercise gradually.[99,100] In fact, some studies have shown that moderate intensity exercise may offer more short-term cognitive benefits than light or vigorous intensity exercise. For example, McMorris and colleagues meta-analyzed 66 acute exercise trials and found that one bout of moderate intensity exercise immediately improved the speed of cognition such as reaction time (effect size: 0.5), while light and vigorous intensity exercise showed no benefits.[101]

Time

Though the WHO and other professional committees/organizations (Table 3), recommend that older adults should exercise 30 minutes/day at moderate intensity and accumulate up to 150 minutes/week,[93,25,94,11,95,96] exercise performed for less than 150 minutes/week can still provide cognitive benefits. For example, Groot and colleagues meta-analyzed 18 exercise training studies among older adults (mean age: 79.7 years) with AD and other types of dementia.[102] Though they found that, independent of the type of dementia, exercise training (i.e., aerobic, dynamic resistance, or combined) performed ~180 minutes/week for 15 weeks significantly improved a variety of cognitive functions.[102] that the cognitive benefits were similar between exercise performed <150 minutes/week and exercise performed ≥150 minutes/week [102]

Type

Currently, most evidence from exercise training studies supports the use of aerobic exercise to improve cognitive functions among older adults with AD. Panza et al. found that interventions that only involved aerobic exercise demonstrated the most favorable effects on cognitive function compared to interventions that combined aerobic and dynamic resistance exercise.[97]

Similarly, short-term exercise studies also support the use of aerobic exercise for cognitive benefits. For example, Tsai and colleagues studied the impact of aerobic exercise (i.e., one 30-minute bout of biking at moderate intensity), dynamic resistance exercise (i.e., one 30-minute bout on weight machines at moderate intensity), and inactivity among 66 older adults (mean age: ~65 years) who were in the early/mild stage of AD.[103] They found that both aerobic and dynamic resistance exercise improved short-term reaction times.

Older adults with AD may receive additional cognitive benefits from performing multi-model exercise, which combines exercise (e.g., walking) with additional motor/cognitive tasks (e.g., reciting the alphabet).[104] For example, Schwenk and colleagues compared a regular and a multi-model exercise training program among 61 older adults (mean age: 81.9 years) with mild-to-moderate AD and other types of dementia.[105] The regular exercise training program included mixed types of exercise (e.g., balance exercise) performed 60 minutes/day for 2 days/week; while the multi-model exercise training program included the same exercise regimen, but combined exercise with cognitive/motor tasks (e.g., catching balls with a partner, solving simple math problems) for 15 minutes in each exercise session. After 12 weeks, they found that dual task ability, improved by 22% in the multi-model exercise training group, compared to just a 2% improvement in the regular exercise training group.[105]

Currently, there is limited evidence to show the influence of dynamic resistance, flexibility or neuromotor exercise on cognitive function among older adults with AD.[11] Nonetheless, these three types of exercise can help older adults to maintain, or even improve physical function and prevent falls.[106,107,108]

The Ex R_x recommendations for adults with AD are summarized in Table 4. Here are the additional special considerations:

- Due to memory loss caused by AD, exercise should be simple, repetitive, and consistent.[109]
- The exercise leader must constantly provide verbal encouragement and support to maintain older adults' interest in the program. Strategies such as emphasizing enjoyment, using music, and involve family and friends as exercise partners can improve adherence to exercise programs.[110,111]
- Morning exercise participation is encouraged to avoid agitation and confusion that occurs in the afternoon known as "sundowning".[112]
- Constant supervision during exercise sessions may be necessary especially during mid-to-late stages of AD.[109]

1.5 Exercise Prescription for the Prevention of Falls and Fall-Related Injuries

Approximately 30% of healthy older adults experience a fall annually, Though many falls are associated with multiple risk factors many are due in part to poor balance.[113] Falls are the leading cause of fatal injury and the most common cause of nonfatal trauma-related hospital admissions among older adults.[114,115] The number of fatal falls, non-fatal fall related injuries, and the cost of medical care related to falls is increasing rapidly. In 2000, there were ~10,000 fatal falls and 2.6 million medically treated non-fatal fall related injuries with associated medical expenses totaling over $19 billion in the US.[116] In 2012, there were ~24,000 fatal falls and 3.2 million medically treated non-fatal fall related injuries with associated medical expenses totaling over $30 billion in the US.[117] Due to aging demographics in the US, total medical costs related to falls is expected to reach $68 billion by 2020.[118]

As previously discussed, several professional committees/organizations recommend neuromotor/balance exercise for older adults who have limited mobility or are at high risk of falling.[93,25,94,11,95,96] There are no specific frequency, intensity, time and type (FITT) Ex R_x recommendations for neuromotor/balance training to prevent falls in older adults.[25,59] As a result, based on expert opinion, the ACSM proposes that older adults should perform neuromotor exercise (e.g., Tai Chi, yoga) for 2 to 3 days/week for 20-30 minutes/day to improve balance.[25]

The ACSM states that,[25,59] to improve balance, exercises should *challenge balance control* by including: 1) progressively difficult postures that gradually reduce the base of support (e.g., two-legged stand, semi tandem stand, tandem stand, one-legged stand); 2) dynamic movements that perturb the center of gravity (e.g., tandem walk, circle turns); 3) stressing postural muscle groups (e.g., hell, toe stands); and 4) reducing sensory input (e.g., standing with eyes closed).[25,59] Sherrington and colleagues meta-analyzed 88 exercise training trials and found that, overall, exercise reduced the rate of falls among older people by 21%.[119] Of note, this meta-analysis included interventions that used different types of exercise (i.e., aerobic, dynamic resistance, neuromotor/balance) alone or in various combinations, and the fall rate reduction did not differ based on the types of exercise included.[119] Researchers then compared high level exercise interventions that challenged balance (i.e., moved of the center of mass, narrowed of the base of support and minimized upper limb support) versus exercise interventions that did not. They found that high level exercise interventions designed to challenge balance reduced the rate of falls by 15% more than exercise interventions that did not; in addition, the reduction in falls was even greater, 39%, when the targeted exercise was done for 180 minutes/week or longer.[119] Of note, these benefits only occurred among community dwelling older adults but not older adults who lived in care facilities.[119]

In addition to challenging balance control, exercise interventions for fall prevention can include various combinations of aerobic, dynamic resistance, neuromotor, and flexibility exercise (i.e., multi-component exercise program).[11] The Centers for Disease Control and Prevention (CDC) published the first evidence-based compendium of effective fall prevention interventions for community-dwelling older adults in 2005, and has updated the content every 5 years. Included interventions are selected from fall prevention programs conducted world-wide. The 2015 edition of the compendium recommends 15 exercise programs for fall prevention,[120] such as the Otago Exercise Program that includes aerobic exercise (i.e., walking for 3 days/week), dynamic resistance exercise (i.e., lower extremity dynamic resistance exercise performed with ankle cuff weights); flexibility exercise (e.g., neck and hip rotation); and neuromotor exercise (e.g., multi-directional walking, picking up objects from the floor).[121,122] Though many of the exercise programs include walking, there is insufficient evidence to support the use of low-intensity walking alone as a primary mode of exercise for the prevention of fall and fall-related injuries among older adults.[11,123,124]

There is however strong evidence showing that multi-component exercise is effective in reducing falls, fall risks, and the incidence of injurious falls among community dwelling older adults.[11] Gillespie and colleagues meta-analyzed 159 fall prevention trials and found that the group and home multi-component exercise training programs reduced the rate of falls by 30%.[125] El-Khoury and colleagues meta-analyzed 10 multi-component exercise training trials and found that exercise training programs reduced the risk of all fall-related injuries by 37% among community dwelling older adults.[126] The risk of fall resulting in a need for medical care was reduced by 30%, the risk of a fall that resulted in a severe injuries (e.g., head trauma or any other injury requiring admission to hospital) was reduced by 43%; and the risk of a fall that resulted in a fracture was reduced by 61%.[126] Unfortunately there is a lack of evidence demonstrating that multi-component exercise can provide the same benefits for older adults who live in care facilities, such as nursing homes and hospitals.[127]

Because of its promising impact on improving balance and preventing falls, Tai Chi has attracted worldwide attention from both the scientific community and the general population. Tai Chi is now one of the most highly recommended exercise modalities for balance improvement and fall prevention.[25,59,120,128] Three of the 15 exercise programs for fall prevention recommended by the CDC are Tai Chi programs.[120,129-131] Tai Chi is a neuromotor exercise derived from Chinese martial art. Tai Chi challenges to balance especially when several Tai Chi movements are emphasized.[132] For example, constant multi-directional stepping, even single leg stance, constant weight shifting between heel and toe, using a semi-squat position and with one's gaze relaxed and not focusing on any particular point during practice. Lomas-Vega and colleagues meta-analyzed 11 Tai Chi exercise training studies among older adults,[133] and found that Tai Chi exercise (ranged from 12 to 26 weeks) reduced the rate of falls and injury-related falls by approximately 43% and 50% within one year after completion of the Tai Chi interventions, respectively; and by 13% and 28% over one year after completion of the Tai Chi interventions, respectively.[133]

Exercise is effective at preventing falls and fall-related injuries among community dwelling older adults. When performing exercise to prevent falls and fall-related injuries, the core principle is to challenge balance control by: 1) including progressively difficult postures that gradually reduce the base of support; 2) involving dynamic movements that perturb the center of gravity; 3) stressing postural muscle groups; and 4) reducing sensory input. An exercise program for fall prevention can include various combinations of aerobic, dynamic resistance, neuromotor, and flexibility exercise; meanwhile, Tai Chi is highly recommended to prevent falls and fall-related injuries. However, there currently insufficient evidence to recommend a specific frequency, intensity, or duration of exercise to prevent falls and fall-related injuries among older adults.

2. An Evidence-based Decision Support System for Meeting the Challenges of Designing an Exercise Prescription for Individuals with Multiple Cardiovascular Disease Risk Factors, Chronic Diseases and/or Health Conditions

As discussed in section 1, comorbidities are highly prevalent among older adults. In the US, more than 60% of older adults will have two or more chronic diseases, more than 25% will have four or more chronic diseases, and almost 10% will have six or more.[134] Therefore, a common challenge for health care and exercise professionals when designing an Ex R_x for an older adult with multiple health issues is deciding which CVD risk factor, or chronic disease to base their Ex R_x on. This decision is important because there is variability in the Ex R_x that most favorably impacts CVD risk factors and other chronic diseases. For example, BP reduction requires lower doses of exercise than the amount of exercise necessary to purposively impact bone density.[25] Here we will introduce an evidence-based decision support system (Figure 1) to help guide Ex R_x choices with deciding which CVD risk factor, or chronic disease or health condition to base the patient's/client's FITT principle of. We will use a case study approach to illustrate the evidence-based decision support system's application.

[INSERT FIGURE 1 HERE]

2.1. The Decision Support System's Step-by-Step Approach

The evidence-based decision support system (Figure 1) is based on strategies recommended in the ACSM Guidelines of Exercise Testing and Prescription, 10th Ed.[25] The user should start *with Step 1* which asks the user to identify the patient's/client's CVD risk factors. This information is usually obtained from the medical health history and/or by reviewing the individual's medical record. Once this information has been gathered, each CVD risk factor is scored using AHA's Life's Simple 7 Health Score.[135] CVD risk factors assessed include BMI/waist circumference, low-density lipoprotein (LDL)/total cholesterol, BP, and fasting glucose.[25,135] The metrics for the AHA's Life's Simple 7 predicts a variety of cardiovascular and non-cardiovascular outcomes including myocardial infarction, stroke, coronary heart disease, depression, cognitive impairment, and cancer.[135]

Step 1 then asks, "Which CVD risk factor places the patient/client at the greatest risk for CVD by having the lowest CVH score?" If the patient/client has no other chronic diseases or health conditions, the CVD risk factor with the lowest "CVH score" is the CVD risk factor that the health care and exercise professional should base their patient's/client's FITT Ex R_x on since this CVD risk factor places the patient/client at the highest risk of developing CVD. However, if two or more CVD risk factors score the lowest and/or the patient/client has other chronic diseases or health conditions, *Strategy A, B,* or *C* should then be used to determine which CVD risk factor, chronic disease, or health condition the health care and exercise professional should base their Ex R_x on. Of note, the strategy chosen should be based on the CVD risk factor or chronic disease or health condition with a FITT Ex R_x that best fits that strategy's description. In Figure 1, under each strategy, an example is provided for: 1) when there is a "CVH risk" score tie among the multiple CVD risk factors that the patient/client presents with; and 2) a chronic disease or health condition to choose from when it is not a CVD risk factor.

Strategy A

Strategy A states: Begin with a FITT Ex R_x for the CVD risk factor, chronic disease, or health condition that is the most limiting regarding the patient's ADLs, and or QoL. For example, an exercise program geared toward improving function and decreasing pain for a patient with OA, may be a higher priority than an exercise program that reduces CVD risk for the same patient.[137]

Strategy B

Strategy B states: Begin with a conservative FITT Ex R_x (start low, go slow). If the patient/client is physically inactive (i.e., has not participated in planned, structured physical activity for at least 30 minutes on at least 3 days/week for at least three months) and/or has little to no previous experience participating in an exercise program, and/or if high volumes of exercise are contraindicated, begin with a conservative FITT Ex $R_{x.}$ For example, a conservative FITT Ex R_x is appropriate for an inactive patient who has fibromyalgia.

Strategy C

Strategy C states: Begin with the FITT Ex R_x that best encompasses the FITT Ex R_x for the other CVD risk factors or chronic diseases or health conditions the patient/client presents with. For example, if both hypertension (e.g., SBP/DBP, 145/92 mmHg) and obesity (e.g., BMI, 31 kg/m^2) have the same level of "CVH risk" score, the FITT Ex R_x for hypertension is appropriate because the Ex R_x for hypertension encompasses the Ex R_x for obesity in terms of exercise *volume*.[67]

Of note, the statement "while considering the client's/patient's preferences, goals, and special considerations" is used throughout the evidence-based decision support system. The patient's/client's preferences may be that they would prefer to exercise in a group or that would prefer to split their routine into smaller bouts throughout the day because they have a busy schedule.

2.2 A Case Study that Illustrates Using the Evidence-based Decision Support System.

Case study: Nancy is a 72-year-old woman with a BMI of 24.0 kg/m^2. She does not smoke. Her resting blood pressure is 118/78 mm Hg, and she is taking hydrochlorothiazide to control her high blood pressure. Her LDL cholesterol is 170 mg/dL, and high-density lipoprotein cholesterol is 42 mg/dL. Nancy has a fasting blood glucose of 132 mg/dL. She was diagnosed with diabetic peripheral neuropathy and frequently experiences periods of numbness, tingling, and pain in her arms and legs which impact her ability to do household chores, go up and down stairs, care for her husband, and spend time with her grandchildren. Nancy is retired but is the primary caregiver for her husband who has been diagnosed with AD. As a result, she rarely does any physical activity. Nancy is seeking your professional guidance to become more physically active in order to manage her symptoms from diabetic neuropathy and also to improve her heart health. She would prefer to exercise at light intensity. See Figure 2 for the completed evidence-based decision support system for this case.

[INSERT FIGURE 2 HERE]

Step #1 is to identify Nancy's CVD risk factors. Nancy presents with five CVD risk factors (i.e., age, sedentary lifestyle, hypertension, dyslipidemia, and diabetes). The AHA's

Life's Simple 7 Cardiovascular Health Scoring is then used to determine which of the scoreable CVD risk factors poses the greatest risk regarding the development of CVD. Nancy's BMI is 24 kg/m^2, and scores 2 "CVH points" since her BMI is considered "ideal CVH" (<25 kg/m^2). However, Nancy's LDL cholesterol is 170 mg/dL, which is scored 0 "CVH points" as it is considered "poor CVH" (>160 mg/dL). Nancy's blood pressure is 118 mmHg systolic and 78 mmHg diastolic, but she is being treated with anti-hypertensive medication, and therefore is considered "intermediate CVH" and receives 1 "CVH point." Finally, Nancy's fasting blood glucose is 132 mg/dL, and therefore she is considered to have diabetes and "poor CVH" ($\geq$126 mg/dL), and she receives 0 "CVH points."

Because Nancy's fasting glucose and LDL cholesterol receive equally the low scores, you can use *Strategy A, B, or C* to decide which CVD risk factor her FITT Ex R_x should be based on. In Nancy's case, since her diabetes has limited her ADLs and QoL more than her dyslipidemia, it would be appropriate to base Nancy's FITT Ex R_x on her diabetes. Finally, when designing Nancy's FITT Ex R_x based on diabetes, the health care and exercise professional would also need to consider Nancy's preference regarding exercise intensity, the amount of time she can dedicate to exercising.

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TABLE 1. Exercise Prescription Recommendations for Individuals with Hypertension Made by Various Professional Committees and Organizations

The *FITT* of the Ex R_x	Professional committee/organization			
	ACC/AHA[103]	BSC[115]	CHEP[129]	CNCCD[114]
Frequency (How often?)		5-7 d/wk	4-7 d/wk	5-7 d/wk, preferably 7 d/wk
Intensity (How hard?)	65-75% $HR_{reserve}$	Moderate[a]	Moderate[a]	Moderate[a]
Time (How long?)	90-150 min/wk	30 min/d	Accumulation of 30-60 min/d	30 min/d, continuous or accumulated
Type (What kind?) *Primary*	Aerobic	Aerobic	Dynamic exercise (Aerobic)	Aerobic
Adjuvant	If dynamic resistance exercise: 90-150 min/wk; 50-80% of 1-RM 6 exercises, 3 sets/exercise, 10 repetition/set If isometric resistance exercise: 4 X 2 min (hand grip), 1 min rest between exercises 30-40% maximum voluntary contraction; 3 session/wk for 8-10 wk	Dynamic resistance exercise: 2-3 d/wk, 1-3 sets, 8-10 exercises (prioritizing unilateral exercises) 10-15 repetitions to moderate fatigue, long rest intervals 90-120s	Dynamic, isometric, or handgrip resistance exercise (no FITT specified)	

Note. Abbr. FITT= Frequency, Intensity, Time, Type of the exercise prescription; Ex R_x = exercise prescription; ACC/AHA=American College of Cardiology and American Heart Association; BSC=Brazilian Society of Cardiology; CHEP=the Canadian Hypertension Education Program; CNCCD= Chinese National Center for Cardiovascular Disease; $HR_{reserve}$=heart rate reserve; $VO_{2reserve}$=oxygen uptake reserve; 1-RM=one repetition maximum.

[a] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

TABLE 1 (continued). Exercise Prescription Recommendations for Individuals with Hypertension Made by Various Professional Committees and Organizations

The *FITT* of the Ex R_x	Professional committee/organization		
	ESH/ESC[113]	ACSM[108]	JNC7[121]
***F*requency (How often?)**	5-7 d/wk	Most, preferably all, days of the week	Most days of the week
***I*ntensity (How hard?)**	Moderate[a]	Moderate[a]	
***T*ime (How long?)**	≥30 min/d	30-60 min/d continuous or accumulated	≥30 min/d
T*ype (What kind?) *Primary	Aerobic	Aerobic	Aerobic
Adjuvant	Dynamic resistance exercise: 2-3 d/wk	Dynamic resistance exercise: 2-3 d/wk 60-80% of 1-RM 8-12 repetitions	

Note. Abbr. FITT= *F*requency, *I*ntensity, *T*ime, *T*ype of the exercise prescription; Ex R_x = exercise prescription; ESH/ESC=the European Society of Hypertension and European Society of Cardiology; ACSM =American College of Sports Medicine; JNC7=Seventh Report of the Joint National Committee; $HR_{reserve}$=heart rate reserve; $VO_{2reserve}$=oxygen uptake reserve; 1-RM=one repetition maximum.

[a] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

TABLE 2. Exercise Prescription Guidelines, Scientific Statements, and Recommendations for Type II Diabetes Mellitus Made by Various Professional Committees and Organizations

The *FITT* of the Ex R_x	Professional committee/organization			
	ADA[136]	**DA**[138]	**BSD**[142]	**CDS**[141]
Frequency (How often?)	3-7 d/wk, no more than 2 consecutive days without exercise	3-7 d/wk, no more than 2 consecutive days without exercise		3-7 d/wk, no more than 2 consecutive days without exercise
Intensity (How hard?)	Moderate to vigorous[a]	Moderate to vigorous[a]	Moderate to Vigorous	Moderate to Vigorous
Time (How long?)	If moderate intensity: ≥150 min/wk If vigorous intensity: ≥75 min/wk[b,c]	If moderate intensity: ≥210 min/wk If vigorous intensity: ≥125 min/wk[b,c]	If moderate intensity: ≥150 min/wk	If moderate intensity: ≥30 min/d
Type (What kind?) *Primary*	Aerobic Prolonged	Aerobic	Aerobic	Aerobic
Adjuvant 1	Resistance[d,e] 2-3 d/wk Moderate to vigorous intensity[a] At least 8-10 exercises with 1-3 sets of 10-15 repetitions to near fatigue	Resistance[d,e] 3 d/wk 2-3 sets, 10-12 repetitions for all major muscle groups.	Resistance 3 d/wk 1 set, 15-20 repetitions; progress to 2 sets, 10-15 repetitions; progress to 3 sets, 8 repetitions	Resistance 2-3 d/wk Moderate to vigorous intensity
Adjuvant 2	Flexibility ≥2-3 d/wk Strength to the point of felling tightness or slight discomfort Hold strength for 10-30 sec; 2-4 repetitions for each exercise			

	Static, or dynamic stretching; yoga			
Adjuvant 3	Balance (for older adults) ≥2-3 d/wk Single leg stance, lower-body and core resistance training; Tai Chi			

Note. Abbr. FITT= *F*requency, *I*ntensity, *T*ime, *T*ype of the exercise prescription; Ex R_x = exercise prescription; ADA=American Diabetes Association; DA=Diabetes Australia; BSD=Brazilian Society of Diabetes; CDS=Chinese Diabetes Society

[a] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

[b] Exercise can be performed in one continuous bout or multiple bouts

[c] Exercise can be performed as an equivalent combination of moderate and vigorous intensity activity

[d] appropriate progression is emphasized

[e] resistance exercise can be performed with machines, or free weights

TABLE 2 (continued). Exercise Prescription Guidelines, Scientific Statements, and Recommendations for Type II Diabetes Mellitus Made by Various Professional Committees and Organizations

The *FITT* of the Ex R_x	Professional committee/organization		
	CDA[137]	ABCD[139]	ACSM[140]
***F*requency (How often?)**	4 d/wk progress to 5d/wk		3-7 d/wk
***I*ntensity (How hard?)**	Moderate to vigorous[a]	Moderate to vigorou[a]	Moderate to vigorous[a]
***T*ime (How long?)**	If moderate intensity: ≥150 min/wk[c]	150 min/week at moderate to vigorous intensity[b,c]	150 min/week at moderate to vigorous intensity[b,c]
T*ype (What kind?) *Primary	Aerobic Prolonged	Aerobic	Aerobic Prolonged
Adjuvant 1	Resistance[d,e] 2-3 d/wk Start at 1 set of 15-20 repetitions	Muscle Strengthening 2 d/wk	Resistance[d,e] 2-3 d/wk Moderate to vigorous intensity[a] At least 8-10 exercises with 1-3 sets of 10-15 repetitions to near fatigue
Adjuvant 2			Flexibility ≥2-3 d/wk Strength to the point of felling tightness or slight discomfort Hold strength for 10-30 sec; 2-4 repetitions foe each exercise Static, dynamic, or proprioceptive neuromuscular facilitation stretching
Adjuvant 3			

Note. Abbr. FITT= *F*requency, *I*ntensity, *T*ime, *T*ype of the exercise prescription; Ex R_x = exercise prescription; ACSM = American College of Sports Medicine; CDA=Canadian Diabetes Association; ABCD=Association of British Clinical Diabetologists;

[a] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

[b] Exercise can be performed in one continuous bout or multiple bouts

[c] Exercise can be performed as an equivalent combination of moderate and vigorous intensity activity

[d] appropriate progression is emphasized

[e] resistance exercise can be performed with machines, or free weights

Table 3. Exercise Prescription Guidelines, Scientific Statements, and Recommendations for Osteoarthritis Made by Various Professional Organizations and Committees

The *FITT* of the Ex R_x	Professional committee/organization			
	ACSM[67]	**Ottawa Methods Group**[165]	**ACR**[166]	**AAOS**[167]
Frequency (how often?)	3–5 d/wk			
Intensity (how hard?)	[a]Moderate to vigorous			
Time (how long?)	If moderate intensity: ≥150 min/wk If vigorous intensity: ≥75 min/wk Or an equivalent combination of the two			
Type (what type?)	Aerobic (low joint stress)	Aerobic (low joint stress, especially walking)	Aerobic (low joint stress)	Aerobic (low joint stress)
Adjuvant 1	Resistance exercise 2–3 d/wk Light to moderate intensity, for all major muscle groups 10-15 repetitions for 2-4 sets	Resistance exercise for lower extremities progressive intensity	Resistance exercise	Resistance exercise
Adjuvant 2	Flexibility exercise 7 d/wk Stretch to point of tightness or slight discomfort Hold static stretch for 10-30 s; up to 10 repetitions for dynamic stretch			
Adjuvant 3		Neuromotor exercise	Neuromotor exercise, based on limited evidence	Neuromotor exercise

Adjuvant 4		Aquatic exercise, based on limited evidence	Aquatic exercise	Aquatic exercise, only if symptomatic

Note. Abbr. FITT= *F*requency, *I*ntensity, *T*ime, *T*ype of the exercise prescription; Ex R_x = exercise prescription ACSM=American College of Sports Medicine; ACR=American College of Rheumatology; AAOS= American Academy of Orthopaedic Surgeons; VO_2R=maximum oxygen uptake reserve; HRR=heart rate reserve; 1-RM=one repetition maximum

[a] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

Table 3 (continued). Exercise Prescription Guidelines, Scientific Statements, and Recommendations for Osteoarthritis Made by Various Professional Organizations and Committees

The *FITT* of the Ex R_x	Professional committee/organization		
	MOVE Committee[168]	**National Collaborating Centre on Chronic Conditions**[169]	**OARSI Expert Panel**[170]
Frequency (how often?)			
Intensity (how hard?)			
Time (how long?)			
Type (what type?)	Aerobic (low joint stress)	Aerobic (low joint stress)	Aerobic (low joint stress, especially walking)
Adjuvant 1	Resistance exercise	Resistance exercise	Resistance exercise quadricep exercise is the most recommended exercise
Adjuvant 2			Flexibility exercise

Note. Abbr. FITT= Frequency, Intensity, Time, Type of the exercise prescription; Ex R_x = exercise prescription; VO_2R=maximum oxygen uptake reserve; HRR=heart rate reserve; 1-RM=one repetition maximum

[a] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

TABLE 4. Summary of the Exercise Prescription Recommendations for Individuals with Hypertension, Type 2 Diabetes Mellitus, Osteoarthritis, and Alzheimer's Disease

The *FITT* of the Ex R_x	Chronic Diseases and Health Conditions			
	Hypertension	Type 2 Diabetes Mellitus	Osteoarthritis	Alzheimer's Disease
***F*requency (How often?)**	On most, and preferably all days of the week	3-7 d/wk; avoid more than two consecutive days without exercise	Same as healthy older adults as tolerated; 3-5 d/wk in addition to diet if weight loss is desired	3-5 d/wk, higher frequency is preferred; Exercise in the morning is preferred
***I*ntensity (How hard?)**	Moderate to vigorous;[a] Moderate intensity exercise is preferred because it offers the best benefit-to-risk ratio; HIIT is an option	Moderate to vigorous;[a] HIIT is an option	Same as healthy older adults as tolerated; Moderate intensity preferred	Same as healthy older adults as tolerated; Moderate intensity is preferred
***T*ime (How long?)**	30 min/d continuously, or in multiple short bouts; Accumulate to 150 min/wk	Time per day based on preference; Accumulate to 150 min/wk	Same as healthy older adults as tolerated; Exercise in short bouts is preferred	150 min/wk; less is still beneficial
***T*ype (What kind?)**	Aerobic exercise as the primary type; supplemented by dynamic resistance exercise	Aerobic and dynamic resistance exercise combined could be more effective than separately; Flexibility and neuromotor exercise recommended due to neuropathic symptoms	Same as healthy older adults; Types of exercise that result in high level of joint stress should be avoided; Aquatic exercise may offer acutely reduce to pain and swelling	Aerobic exercise as the primary type; supplemented by dynamic resistance, flexibility, and neuromotor exercise

Note. Abbr. FITT= *F*requency, *I*ntensity, *T*ime, *T*ype of the exercise prescription; Ex R_x = exercise prescription; [a] Moderate intensity is defined as 40-59% oxygen uptake reserve or heart rate reserve, 64-76% maximal heart rate, 46-63% maximal oxygen uptake, 12 to 13 on rating of perceived exertion, or an intensity that causes noticeable increases in heart rate and breathing for aerobic exercise, or 50-69% of one repetition maximum for resistance/muscle strengthening exercise; vigorous intensity is defined as 60-89% oxygen uptake reserve or heart rate reserve, 77-95% maximal heart rate, 64-90% maximal oxygen uptake, 14 to 17 on rating of perceived exertion, or an intensity that causes substantial increases in heart rate and breathing (out of breath) for aerobic exercise, or 70-84% of one repetition maximum for resistance/muscle strengthening exercise

Start Here

Step 1
Identify the patient's/client's CVD risk factors, chronic diseases, and health conditions.

Score each CVD risk factor using the AHA's Life's Simple 7 Health Scoring.[a]

CVD Risk Factor	Score
Body Mass Index/Waist	_____
LDL (or Total)[b] Cholesterol	_____
Blood Pressure	_____
Fasting Glucose	_____

Which CVD risk factor places the patient/client at the greatest risk for CVD by having the lowest CVH score?

If the patient/client has no other chronic health conditions or diseases, begin with the FITT Ex R_x for this CVD risk factor while considering the patient's/client's preferences, goals, and special considerations.

If >1 CVD risk factor scored lowest and/or the patient/client has other chronic diseases or health conditions, use *Strategy A, B, or C* to determine which CVD risk factor, health condition, or disease should be used.[c]

Strategy A
Begin with the FITT Ex R_x for the single CVD risk factor or chronic disease or health condition that is the most limiting regarding activities of daily living (ADLs), quality of life (QOL), and/or starting or maintaining an exercise program while considering the patient's/client's preferences, goals, and special considerations.

Client example: Patient/client with a disease or condition that is physically limiting

CVH score tie example: Diabetes with neuropathy may be more limiting than an LDL cholesterol ≥160

Non-CVD factor risk example: Severe osteoarthritis

Strategy B
Begin with the most conservative (i.e., less demanding and less complex) FITT Ex R_x regarding the intensity and/or volume of exercise considering the patient's/client's multiple CVD risk factors or chronic diseases or health condition, while considering the patient's/client's preferences, goals, and special considerations.

Client example: Non-physically active, novice to exercise

CVH score tie example: Ex R_x volume for diabetes is more conservative (i.e, less demanding and less complex) than Ex R_x volume for hypertension

Non-CVD risk factor example: Fibromyalgia

Strategy C
Begin with the FITT Ex R_x that best encompasses the FITT Ex R_x for the other CVD risk factors or chronic diseases or health conditions the patient/client presents with, while considering the patient's/client's preferences, goals, and special considerations.

Client example: Patient/client with multiple diseases, health conditions, and/or CVD risk factors that may be of similar risk

CVH score tie example: Ex R_x volume for blood pressure encompasses Ex R_x volume for obesity

Non-CVD risk factor example: Ex R_x volume for COPD encompasses Ex R_x volume for asthma

American Heart Association's Life's Simple 7 Cardiovascular Health Scoring

CVH Metric	Ideal CVH definition (2 points)	Intermediate CVH definition (1 point)	Poor CVH definition (0 points)
Body Mass Index/ Waist Circumference[d]	<25 kg/m^2	25-29.9 kg/m^2	≥30 kg/m^2 or waist circumference >102 cm (40 in) for men and >88 cm (35 in) for women
Low Density Lipoprotein/ Total Cholesterol	<100 mg/dL <170 mg/dL	100-159 mg/dL 170-199 mg/dL	≥160 mg/dL ≥200 mg/dL
Blood Pressure	<120/<80 mmHg	SBP: 120-139 mmHg and/or DBP: 80-89 mmHg or treated to <120/<80 mmHg	SBP ≥140 mmHg and/or DBP ≥90 mmHg
Fasting Glucose	<100 mg/dL	100-125 mg/dL	≥126 mg/dL (diabetes)

Note. ADLs = activities of daily living; AHA = American Heart Association; COPD = chronic obstructive pulmonary disorder; CVD = cardiovascular disease; CVH = cardiovascular health; Ex R_x = exercise prescription; *FITT* = frequency, intensity, time, and type; LDL = low density lipoprotein; QOL = quality of life.

Ex R_x for individuals with multiple diseases and health conditions generally follows the recommendations for healthy adults except when a disease or condition dictates a more conservative approach.

[a] There is a strong, inverse association between AHA Life's Simple 7 ideal metrics and the incident of myocardial infarction, stroke, coronary heart disease, and other cardiovascular outcomes, as well as non-cardiovascular conditions like depression, cognitive function, and cancer (Folsom, Aaron R., et al. *The American journal of medicine.* 128(9) (2015): 970-976).

[b]Total cholesterol is only scored if LDL is not available.

[c]The strategy chosen should be based on the CVD risk factor, health condition, or disease with a *FITT* ExR_x that best falls under the strategy's description while considering the client's/patient's preferences, goals, and special considerations.

[d]Risk cut-offs for waist circumference are based on Table 3.1 in *ACSM's Guidelines for Exercise Testing and Prescription, 10th edition.*

See chapter 10 and chapter 11 in *ACSM's Guidelines for Exercise Testing and Prescription, 10th edition* for the Ex R_x and special considerations for each CVD risk factor, chronic condition, and disease and additional recommendations for individuals with multiple chronic diseases and health conditions, respectively.

Instruction for Step 1: Each CVD risk factor is scored with "cardiovascular health (CVH)" points based upon the level of CVD risk that ranges from "ideal CVH" (2 CVH points) to "intermediate CVH" (1 CVH point), to "poor CVH" (0 CVH points). The user then puts the number of "CVH points" in the blank spaces provided next to each CVD risk factor under *Step 1*. Of note, the patient's/client's total cholesterol is only scored if LDL cholesterol is not available because LDL cholesterol is a better indicator of CVD risk. In addition, if the patient's/client's waste circumference is >102 cm (40in) for men, or >88cm (35in) for women, they receive 0 "CVH points" regardless of their BMI since values above these cut-offs put the patient/client at increased- to high-risk of developing CVD.

Figure 1. An Evidence-Based Decision Support System for Determining Which Cardiovascular Disease Risk Factor, Chronic Disease or Health Condition to Base the Exercise Prescription on

Start Here

Step 1
Identify the patient's/client's CVD risk factors, chronic diseases, and health conditions.

Score each CVD risk factor using the AHA's Life's Simple 7 Health Scoring.[a]

CVD Risk Factor	Score
Body Mass Index/Waist	2
LDL (or Total)[b] Cholesterol	0
Blood Pressure	1
Fasting Glucose	0

Which CVD risk factor places the patient/client at the greatest risk for CVD by having the lowest CVH score?

If the patient/client has no other chronic health conditions or diseases, begin with the FITT Ex R_x for this CVD risk factor while considering the client's/patient's preferences, goals, and special considerations.

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Client example: Patient/client with a disease or condition that is physically limiting

CVH score tie example: Diabetes with neuropathy may be more limiting than an LDL cholesterol ≥160

Non-CVD factor risk example: Severe osteoarthritis

Strategy B
Begin with the most conservative (i.e., less demanding and less complex) FITT Ex R_x regarding the intensity and/or volume of exercise considering the patient's/client's multiple CVD risk factors or chronic diseases or health condition, while considering the patient's/client's preferences, goals, and special considerations.

Client example: Non-physically active, novice to exercise

CVH score tie example: Ex R_x volume for diabetes is more conservative (i.e, less demanding and less complex) than Ex R_x volume for hypertension

Non-CVD risk factor example: Fibromyalgia

Strategy C
Begin with the FITT Ex R_x that best encompasses the FITT Ex R_x for the other CVD risk factors or chronic diseases or health conditions the patient/client presents with, while considering the patient's/client's preferences, goals, and special considerations.

Client example: Patient/client with multiple diseases, health conditions, and/or CVD risk factors that may be of similar risk

CVH score tie example: Ex R_x volume for blood pressure encompasses Ex R_x volume for obesity

Non-CVD risk factor example: Ex R_x volume for COPD encompasses Ex R_x volume for asthma

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Fasting Glucose	<100 mg/dL	100-125 mg/dL	≥126 mg/dL (diabetes)

Note. ADLs = activities of daily living; AHA = American Heart Association; COPD = chronic obstructive pulmonary disorder; CVD = cardiovascular disease; CVH = cardiovascular health; Ex R_x = exercise prescription; *FITT* = frequency, intensity, time, and type; LDL = low density lipoprotein; QOL = quality of life.

Ex R_x for individuals with multiple diseases and health conditions generally follows the recommendations for healthy adults except when a disease or condition dictates a more conservative approach.

[a] There is a strong, inverse association between AHA Life's Simple 7 ideal metrics and the incident of myocardial infarction, stroke, coronary heart disease, and other cardiovascular outcomes, as well as non-cardiovascular conditions like depression, cognitive function, and cancer (Folsom, Aaron R., et al. *The American journal of medicine.* 128(9) (2015): 970-976).

[b] Total cholesterol is only scored if LDL is not available.

[c] The strategy chosen should be based on the CVD risk factor, health condition, or disease with a *FITT* ExR_x that best falls under the strategy's description while considering the client's/patient's preferences, goals, and special considerations.

[d] Risk cut-offs for waist circumference are based on Table 3.1 in *ACSM's Guidelines for Exercise Testing and Prescription, 10th edition.*

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Figure 2. Case Study: An Evidence-Based Decision Support System for Determining which Cardiovascular Disease Risk Factor, Chronic Disease or Health Condition to Base the Exercise Prescription on

Chapter 3-A. Evaluating Exercise Prescription and Instructional Methods Used in Tai Chi Studies Aimed at Improving Balance in Older Adults: A Systematic Review

Yin Wu, MA, Hayley V. MacDonald, PhD, and Linda S. Pescatello, PhD

Department of Kinesiology, College of Agriculture, Health and Natural Resources, University of Connecticut, Storrs, Connecticut

Address correspondence to: Yin Wu, Department of Kinesiology, College of Agriculture, Health and Natural Resources, University of Connecticut, 2095 Hillside Rd Unit 1110, Storrs, CT 06269. E-mail: yin.2.wu@uconn.edu

Abstract

Objectives: To develop an evaluation instrument to determine to what extent Tai Chi interventions aimed at improving the balance of older adults disclosed their exercise prescription (Ex R_x) and instructional methods and met best-practice exercise recommendations for balance improvement.

Design: Review.

Setting: PubMed, Scopus, and CINAHL databases were searched from their inception until August 22, 2014.

Participants: Adults aged 60 and older without debilitating disease.

Measurements: Three electronic databases were searched to identify randomized controlled trials (RCTs) of Tai Chi interventions aimed at improving balance in older adults without severe debilitating diseases. Three Ex R_x (frequency, time, intervention length) and 10 instructional (e.g., style, number of forms) methods of the included RCTs were evaluated.

Results: Twenty-six interventions were identified from 27 RCTs. On average, Tai Chi was performed for a mean 56.5±14.4 minutes per session for 2.8±1.4 sessions per week for 19.7±12.7 weeks. Most interventions reported all three Ex R_x methods items, with a mean reporting rate of 92.6±19.2%. For the 10 instructional methods items, the mean reporting rate was 41.1±18.0%, significantly lower than for the Ex R_x methods items ($p<.001$). Fewer than half of the interventions reported unsupervised practice (15%), progression (22%), or the use of breathing (30%) and relaxation (15%) techniques. The instructional methods items most important for targeting Tai Chi practice to improve balance were not routinely disclosed, with only 15% reporting names of forms and 52% reporting movement principles.

Conclusion: Most Tai Chi interventions disclosed their Ex R_x methods yet routinely failed to report instructional methods. To increase the effectiveness of Tai Chi to improve balance in older adults, future RCTs should disclose their Ex R_x and instructional methods, especially methods that target balance.

Key words: fall prevention, elderly, neuromotor exercise, physical activity, sensorimotor control

Introduction

Approximately 30% of healthy, older adults experience a fall annually, largely due to age-related decrements in balance.[39] Tai Chi has the potential of improving balance because of its unique movement characteristics.[46] For example, Tai Chi movements require accurate joint positioning and constant weight shifting that involves the neck, trunk, and limbs, all of which may lead to improved sensorimotor control of balance.[60]

Tai Chi was originally created in China as a form of martial arts nearly 400 years ago, and was practiced mainly for combat purposes.[19] Over its long evolutionary process, Tai Chi developed into five major styles (i.e., Chen, Yang, Sun, Wu, Hao) and over 108 forms.[19,20] In 1956, the Chinese government simplified Tai Chi practice by creating a 24-form Yang style Tai Chi routine that became available for public use as a form of exercise.[19] Surprisingly, from its time of conception to now, the purposes of Tai Chi were not to target any specific health outcomes.[20]

Currently, Tai Chi is one of the most popular types of exercise in the United States that is recommended to improve balance for the purposes of fall prevention among older adults.[13] However, specific guidelines for tailoring Tai Chi exercise for balance improvement have yet to be developed. Sherrington and colleagues[50] published the first and only evidence-based best practice exercise recommendations for balance improvement, of which the core principle is to provide moderate-to-high levels of challenge to balance by using movements such as reducing the base of support and moving the center of gravity. Nonetheless, these best practice exercise recommendations are not specific to Tai Chi, nor have they been applied to Tai Chi interventions aimed at improving balance.[13] In general, Tai Chi has been shown to be effective at improving balance among a diverse sample of older adults, but such improvements are not consistent across studies.[45-49] Researchers have speculated that the widely varying exercise prescription (Ex R_x)

and instructional methods reported across Tai Chi interventions are the primary contributors to the inconsistencies in this literature.[45-49]

Therefore, we developed a 13-item evaluation instrument that included fundamental items of Ex R_x and instructional methods most relevant to Tai Chi practice. Then using this instrument, we systematically reviewed and evaluated Tai Chi studies aimed at improving balance among older adults (≥60 yr) without severe debilitating diseases to better inform Tai Chi practice as a balance improvement and fall prevention strategy.

Methods

Evaluation Instrument Development

We developed a Tai Chi evaluation instrument based upon the expertise of our interdisciplinary research group in the areas of high quality, contemporary systematic reviews (HVM, LSP),[61,62] Tai Chi practice (YTW, YW)[63] and Ex R_x (LSP),[13] named the *Tai Chi Ex R_x and Instructional Methods Evaluation Tool (TaCIE)* (see Table 1 for a detailed explanation). One member of our research team (YW) developed the initial *TaCIE* evaluation instrument; the others critiqued the scale and suggested improvements (LSP, HVM, YTW). The scale items were finalized by the senior investigator and expert in Ex R_x methods (LSP)[13] and a university professor with experience in both practicing and conducting Tai Chi interventional studies (YTW).[63,64]

TaCIE Part 1: Ex R_x Methods

Consisted of three items that integrated the components of the FITT-VP (*F*requency, *I*ntensity, *T*ime, *T*ype, *V*olume, and *P*rogression) principle of Ex R_x most relevant to Tai Chi practice.[13] We selected the following items for inclusion in the *TaCIE* Ex R_x methods: 1)

*F*requency of Tai Chi practice (sessions/week); 2) *T*ime or duration of each Tai Chi session (minutes/session); and 3) length of the Tai Chi intervention (weeks).

TaCIE Part 2: Instructional Methods

Consisted of items that integrated information from several systematic reviews,[46,47,49,65,66] meta-analyses,[67,68] and a two-part methodology paper of Tai Chi studies.[69,70] From these resources, we identified several items for inclusion on the *TaCIE* that met the following *a priori* criteria: 1) Items were fundamental to Tai Chi practice; 2) Items were specific to Tai Chi practice; and 3) Items were modifiable/controllable in a Tai Chi intervention.[69] Ultimately, we selected 10 items for inclusion in the *TaCIE* Instructional Methods: Items 1-3 described the Tai Chi routine: 1) Style, 2) Number of Forms, and 3) Names of Forms; Items 4-6 encompassed the basic elements of Tai Chi that should be emphasized during practice: 4) Movement Principles, 5) Breathing Techniques, and 6) Relaxation; and Items 7-10 described how Tai Chi practice was delivered in the intervention: 7) Progression, 8) Credentials of Instructor, 9) Number of Instructors, and 10) Unsupervised Practice. Of these 10 instructional methods items, the name of forms and movement principles (items 3 and 4), are the most important for balance improvement, as they directly affect the level of challenge to balance provided by Tai Chi practice.[50]

Literature Search and Selection Criteria

Qualifying articles were retrieved from electronic databases (i.e., PubMed, Scopus, and CINAHL) from their inception until August 22, 2014 with key words related to: 1) “Tai Chi”; 2) “balance”; and 3) “older adults”. Studies were included if they were published in English and met the following criteria: 1) targeted balance improvement as the primary study outcome; 2) followed a randomized controlled trial (RCT) study design in which participants received Tai

Chi *only* in at least one intervention group; and 3) involved adult participants without severe debilitating disease (e.g., Parkinson's disease) aged ≥60 yr. Our initial search resulted in 643 records, and of those, 26 RCTs (27 Tai Chi interventions) were included in this review (see Figure A1 for the flow diagram).[71-96]

Data Extraction and Coding

In addition to the *TaCIE* (Table 1), two trained coders extracted the following information for each qualifying Tai Chi intervention: 1) study characteristics (e.g., author, publication year); 2) sample characteristics (i.e., age, gender, health status); 3) methodological study quality; and 4) balance outcomes (i.e., whether significant improvements in balance were reported). Coders exhibited high reliability and agreement (Pearson's r=91.8% and mean corrected Cohen's κ= 0.90). Disagreements between coders were resolved through discussions with the senior investigator (LSP).

Methodological study quality was assessed using an augmented version of the Downs and Black checklist[97] (27 items), and was reported as the percentage of items satisfied out of a possible 31 total points. Ranges in overall methodological study quality scores were grouped into three quality levels: low (≤15 points, <50%), moderate (>15 to 24 points, 50-79%), and high (≥25 points, ≥80%).[98,99]

Tai Chi interventions used a variety of balance assessments (Table 2). Therefore, we coded balance outcomes as 1 (=*Yes*) when authors reported significant improvements in *any* measure of balance for the Tai Chi group post- versus pre-intervention (i.e., *within-group*) *or* post-intervention versus control. If no significant improvements were reported by the authors for Tai Chi groups, balance outcomes were coded as -1 (=*No*) (Table 2).

Statistical Analysis

Descriptive statistics were calculated for baseline sample and Tai Chi intervention characteristics. Continuous variables are expressed as *M*ean±standard deviation (*SD*), when applicable. The reporting rate (i.e., percentage of items satisfied) of the *TaCIE* items for Part 1: Ex R_x Methods and Part 2: Instructional Methods were tabulated as:

$$=(\text{number of interventions that reported the item}/\text{total number of interventions}) \times 100\%$$

Unpaired *t*-tests were used to test for differences in: 1) baseline sample characteristics between the control and Tai Chi groups; and 2) the mean reporting rate between the Ex R_x and instructional methods items. Pearson correlations were used to evaluate the association between the balance outcomes and total methodological study quality, reporting rate for Ex R_x and instructional methods items, and other coded features of the Tai Chi interventions (e.g., sessions/week). All analyses were performed using IBM SPSS Statistic 21 (Armonk, NY: IBM Corp). The two-tailed significance level was set at $p \leq 0.05$.

Results

Baseline Sample Characteristics

Baseline sample characteristics are presented in Table 3. Overall, our sample (N=3247) consisted of a majority of women (64.7%) with a mean age of approximately 73 years. Almost half (40.7%) of included interventions enrolled healthy, older adults with no reported disease(s) or health conditions (not reported by one study). Nonetheless, a small number of included interventions involved participants with disease(s) or health conditions including: osteoporosis and osteopenia (11.3%), frailty (3.7%), vision impairment (3.7%), diabetes mellitus (3.7%), and dizziness (3.7%). In addition, 29.6% of Tai Chi interventions enrolled older adults who were at high risk of falling. There were no significant differences in baseline characteristics between the Tai Chi and control groups (*p*>0.05).

TaCIE Part 1: Ex R_x Methods

A summary of the Ex R_x method items of the 27 Tai Chi interventions is presented in Supplemental Table 4. Overall, Tai Chi exercise was practiced ~3 sessions/week, 55-60 minutes/session, for ~20 weeks.

TaCIE Part 2: Instructional Methods

A summary of the instructional method items of the 27 Tai Chi interventions is presented in Table 5. Tai Chi routines included 15 forms, following one of three styles: Yang, Sun or Chen. Interventions averaged three Tai Chi instructors with credentialing as experienced, certified/qualified, or Tai Chi master. The two items that directly affect the level of challenge to balance provided by Tai Chi practice, name of forms and movement principles, were only reported by four (14.8%) and 14 (51.9%) interventions, respectively. A general description of each Tai Chi intervention is provided in Table 6, including an item-by-item summary of Part 1 and 2 of the *TaCIE.*

Reporting Rate of Ex R_x and Instructional Methods Items

Overall, the mean reporting rate of the Ex R_x methods items was high totaling 92.6%±19.2%, whereas the mean reporting rate of the instructional methods items was significantly lower totaling 41.1%±18.0% ($p<.001$). The reporting rate for the three Ex R_x and 10 instructional methods items are presented in Tables 4 and 5, respectively.

Methodological Study Quality, Balance Outcomes and Correlations

Included interventions achieved “moderate” or “fair” methodological study quality,[99] ranging from 44.8%-86.2% of items satisfied. Only four (14.8%) Tai Chi interventions satisfied

≥80% of the items on the augmented Downs and Black checklist,[97] suggesting the included interventions were of lower quality.

Balance improvements were reported in 19 out of the 27 interventions (Table 2). However, balance improvements were not related to overall methodological study quality, nor were they related to the mean reporting rate of the Ex R_x and instruction methods items (see Table 7). When we examined the relationship between improved balance and individual *TaCIE* items, only the reporting rate of movement principles marginally correlated with balance improvements following Tai Chi (r=0.35, p=0.08) (Table 7).

Discussion

We developed an evaluation instrument, *TaCIE* (Table 1) to determine to what extent Tai Chi studies aimed at improving balance among older adults: 1) disclosed their Ex R_x and instructional methods; and 2) met Sherrington et al.'s[50] best practice exercise recommendations for balance improvement.

Overall, the mean reporting rate of the Ex R_x methods items was high (~93%), with 23 of the 27 interventions reporting all three items. In contrast, the mean reporting rate of the 10 instructional methods items was low (~42%), and none of the Tai Chi intervention reported all 10 instructional methods items. Unfortunately, the two instructional methods items that directly influence the level of challenge to balance of Tai Chi practice[50], name of forms and movement principles, were poorly reported. Only 14.8% of Tai Chi interventions reported name of forms, while 51.9% of the interventions reported movement principles.

Sherrington et al.'s best-practice exercise recommendations for balance improvement call for movements that provide moderate to high levels of challenge for maintaining balance.[50] In addition, the American College of Sports Medicine[13] and American Geriatric Society[100] have made similar recommendations for exercise targeted at balance improvement. Therefore, researchers using Tai Chi exercise for the purpose of improving balance should integrate and disclose the: 1) Tai Chi forms used to challenge balance;[101] and 2) movement principles that increase the difficulty of maintaining balance by moving the center of gravity.[4,17,19]

Surprisingly, only four interventions (15%) reported the name of the Tai Chi forms[S3:4,5,17,25]. Of the 108 traditional Tai Chi forms that could be integrated,[20] "kick with heel" is one of the most challenging,[101] because it requires participants to stand on one leg, lift the other leg, and then extend the knee in a slow and controlled manner.[102] However, this form was included in only one of the four interventions that reported the name of forms.[S3:25] In addition, none of these four interventions stated "balance improvement" as the rationale for selecting their specific combinations of Tai Chi forms.

Movement principles such as "weight shifting between legs and from heel to toe" and "multi-directional stepping" provide the potential to improve balance because they challenge the center of gravity during Tai Chi practice.[46] Yet, nearly half of the Tai Chi interventions (k=13, 48%) failed to disclose any movement principles. Among the 14 interventions that reported integrating movement principles, 11 (78.6%) emphasized at least one of the two movement principles (i.e., weight shifting and multi-directional stepping); seven interventions (50.0%) emphasized both; and three (21.4%) interventions included movement principles unrelated to balance (e.g., slow and smooth movement). These two instructional method items, name of forms and movement principles, should be the foundation of Tai Chi practice for any intervention study aimed at improving balance.[50] Nonetheless, our review found that researchers rarely tailored their Tai Chi interventions based on these two items in order to maximize the level of challenge provided by Tai Chi practice in accordance with best-practice exercise recommendations for balance improvement.[50]

Encouragingly, we found that balance was significantly improved in 19 out of 27 interventions; however, these interventions on average were of “fair” methodological study quality. It is noteworthy to mention that neither the Ex R_x methods items reporting rate (r = 0.04, p=0.86), nor the instructional methods items reporting rate (r = 0.33, p=0.09) were significantly correlated with the methodological study quality of Tai Chi interventions. These observations emphasize that the issues we observed regarding the poor reporting of important Tai Chi intervention details are consistent across the Tai Chi and balance literature, even among those that achieved higher study quality (mean reporting rate: Ex R_x=100%; Instructional Methods=50%).[S3:12,18,19]

We also explored the relationship between individual *TaCIE* items and balance improvements among older adults. Despite the fact that Ex R_x method items were significantly better reported than instructional methods items, none of these items (*F*requency, *T*ime, and Length of intervention) were correlated with improved balance outcomes (p>0.20). Instead, we observed a moderate correlation between the reporting of movement principles and balance improvement (r=0.35, p=0.08). Studies that included *any* movement principles showed a greater tendency towards improved balance outcomes, even though researchers did not intentionally utilize movement principles to increase the level of challenge to balance. These findings suggest the process to which Tai Chi improves balance may be more complex than a dose-response relationship achieved with traditional Ex R_x components.[103,104]

Balance improvement is one of the well-established health outcomes for practicing Tai Chi among older adults.[12,13] Our results showed that important and Tai Chi-specific features of the intervention (i.e., instructional methods) were poorly reported, with the exception of those items related to the traditional FITT-VP principle.[13] In addition, these features were not tailored for the purpose of balance improvement, even though the instructional methods items may be the most influential in determining the effectiveness of Tai Chi exercise for improving balance among older adults. Our review emphasizes the need for additional Tai Chi RCTs specifically designed to target balance improvement to determine not only the optimal Ex R_x but also the combination of instructional methods that maximize the effectiveness of Tai Chi exercise for balance improvement and fall prevention strategy.

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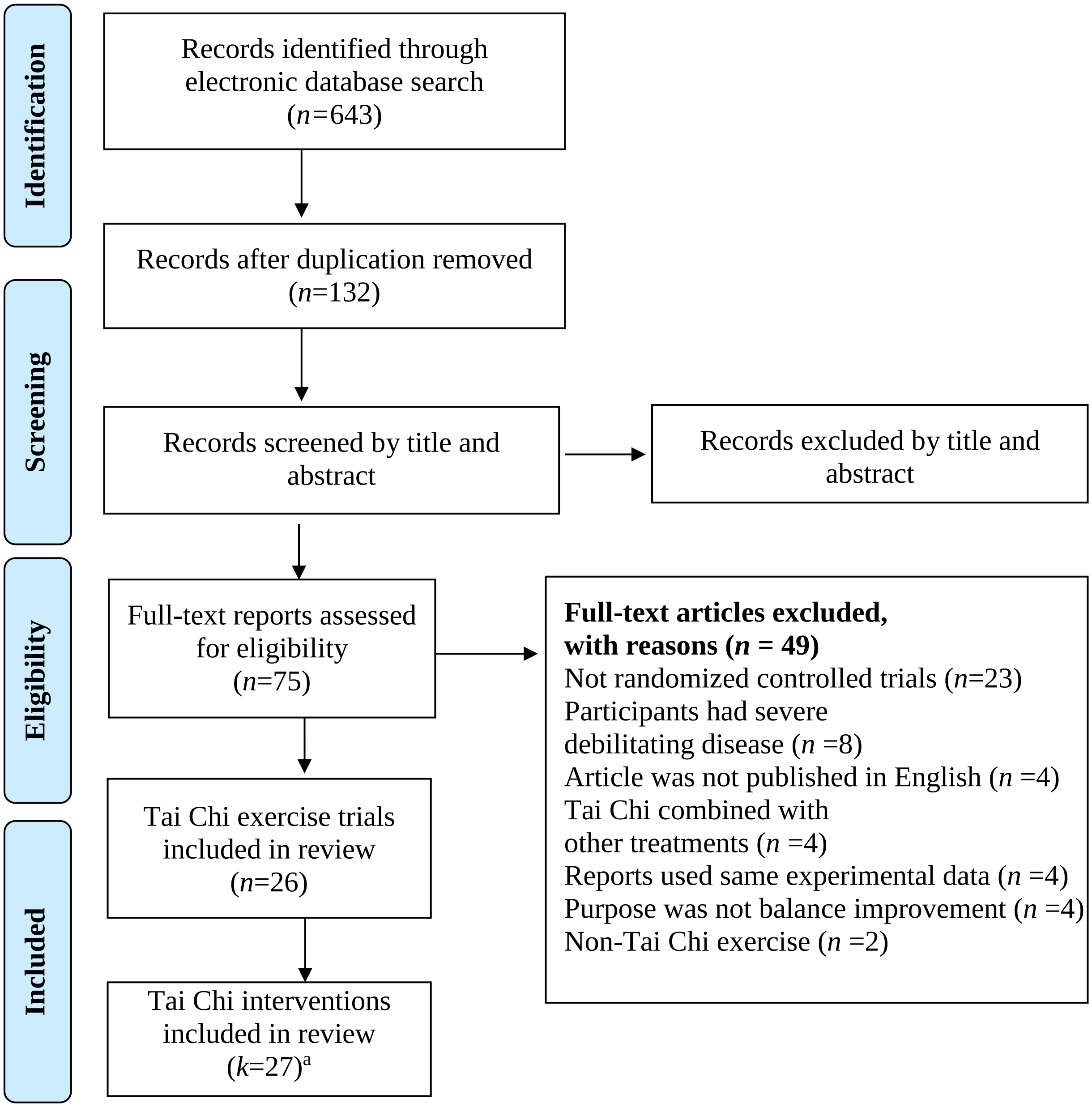

Figure A1. Flow chart detailing the systematic search of potential reports (*n*) and selection process of included Tai Chi interventions (*k*)
Note. [*] Taylor et al., 2012 (Supplemental Reference 18) had two Tai Chi exercise intervention groups. ***Abbr.*** RCT = randomized controlled trials

Table 1. The Tai Chi exercise prescription and Instructional methods Evaluation tool (*TaCIE*).

Items	Rationale	Yes/No
Part I: Exercise Prescription (Ex R_x) Items		
Time	**Did authors report the time of each session?** If the length of each session changed over time, length of each session has to be reported for each time period (i.e., minutes/session).	_______
Length	**Did authors report the duration (weeks) of the intervention?**	_______
Frequency	**Did authors report frequency as the number of sessions per week?** If the frequency changed over time, frequency has to be reported for each time period (i.e., sessions/week).	_______
Part II: Instructional Methods Items		
Style	**Did authors report the style of Tai Chi?** Style is the different lineages that Tai Chi developed into over the years (e.g., Yang, Chen).[1]. Code NO if the style of Tai Chi was described as “simplified”, “modified”, or “traditional”.	_______
Number of Forms	**Did authors report the number of forms selected for the Tai Chi routine?** The number of Tai Chi forms included in the routine (e.g., 12 or 24 form-routines).	_______
Name of Forms	**Did authors report the name of Tai Chi forms selected for the routine?** Tai Chi form is the series of movements and postures with a given name (e.g., “wave hands like clouds”, “single whip”).[2]	_______
Movement Principle	**Did authors clearly state that movement principles were emphasized during practicing?** Movement principles are the general rules of performing Tai Chi forms (e.g., practitioners should pay attention to exact joint positioning when practicing Tai Chi).[3]	_______
Breathing Techniques	**Did authors clearly state that breathing techniques were emphasized during practicing?** Breathing techniques are the specific methods of breathing that should be adopted during Tai Chi practice (e.g., continuous diaphragmatic breathing).[2] Code NO if breathing techniques were only emphasized in warm up or cool down.	_______
Relaxation	**Did authors clearly state that relaxation was emphasized during practicing?** Relaxation is the mental state of concentration, calm and tranquility.[4] Code NO if relaxation was only emphasized in warm up or cool down.	_______

Progression	**Did authors clearly state certain progression of Tai Chi practice was adopted?** Progression is the method that allows participants to gradually learn and adapt to the Tai Chi routine and improve skills of practicing Tai Chi (e.g., review Tai Chi forms taught previously at the beginning of each class; or allow participants using assistive devices at the beginning, but progress to practice without those devices).[5]	_______
Instructor Credentials	**Did authors report the credential of the Tai Chi instructors?** Credential is the qualifications of instructors leading Tai Chi practice (e.g., experienced, qualified, Tai Chi masters).[6]	_______
Number of Instructors	Did authors report the number of instructors hired in the entire study? The number of Tai Chi instructors that led the intervention.[6]	_______
Unsupervised practice	**Did researchers report instructions regarding unsupervised practice?** Unsupervised practice is tai Chi practice performed outside of supervised classes (e.g., participants were encouraged to practice Tai Chi outside the class and record the amount of practice with an exercise log).[7]	

Table 2. Summary of balance measurements and balance outcomes for each Tai Chi intervention (*k*=27).

Author, Year	Control Group Activity	Balance Measurements	Finding Significant Balance Improvement		
			Within Group [a]	Between Groups [b]	Coding [c]
Audette et al., 2006	Brisk walking	Single leg stance test	X	X	-1
Chen et al., 2012	Play instrument	Sensory organization test	X	Yes	1
Chyu et al., 2010	No exercise	Sensory organization test Motor control test Adaptation test Timed up and go test	No	No	-1
Frye et al., 2007	No exercise	Timed up and go test	Yes	X	1
Gatt and Marjorie, 2006	Balance training	Timed up and go test Functional reach test Single leg stance test Tandem stance test	Yes	No	1
Hass et al., 2004	Education	Force platform indicator[d]	X	Yes	1
Huang et al., 2010	Usual care	Timed up and go test Functional reach test	Yes	X	1
Kim, 2009	Usual activity	Force platform indicator	Yes	X	1
Kim, Han, and Cho, 2009	Education	Force platform indicator	Yes	Yes	1
Lalard et al., 2010	Balance training	Force platform indicator	No	No	-1

Li et al., 2005	Stretching	Berg balance test Dynamic gait index Functional reach Timed up and go	X	Yes	1
Li, Xu, and Hong, 2008	Usual activity	Single leg stance	Yes	Yes	1
Logghe et al., 2009	Usual care	Berg balance test	No	No	-1
Maciaszek et al., 2007	Usual activity	Force platform indicator	Yes	Yes	1
Maciaszek and Osinski, 2012	Usual activity	Timed up and go test Force platform indicator	Yes	Yes	1
Ni et al., 2014	Yoga	Timed up and go test Single leg stance Force platform indicator	Yes	No	1
Pluchino et al., 2012	Balance training	Timed up and go test Single leg stance test Functional reach test Tinetti performance oriented mobility assessment Force platform indicator	Yes	No	1
Song et al., 2014	Usual activity	Stepping test	Yes	Yes	1
Song et al., 2003	Usual activity	Single leg stance test	Yes	Yes	1
Taylor et al., 2012 (group 1)	Light exercise	Timed up and go test Stepping test	No	No	-1

		Chair stand test			
Taylor et al., 2012 (group 2)	Light exercise	Timed up and go test Stepping test Chair stand test	No	No	-1
Taylor-Piliae et al., 2010	Education	Single leg stance test Functional reach test	X	Yes	1
Tsang et al., 2007	Stretching	Single leg stance test Tandem walk test	Yes	No	1
Voukelatos et al., 2007	Usual activity	Force platform indicator	X	Yes	1
Woo et al., 2007	Usual activity	Single leg stance test	X	No	-1
Wolf et al., 1997	Education	Force platform indicator	No	No	-1
Zhang et al., 2006	Usual activity	Single leg stance	X	Yes	1

Note. X indicates the comparison was not reported in the intervention.

[a] Comparison of balance outcomes within Tai Chi group post- versus pre-intervention.

[b] Comparison of balance outcomes of Tai Chi group post-intervention versus control.

[c] 1 indicates significant balance improvement was reported by authors for either within-group or between-groups; -1 indicates significant balance improvement was reported by authors for neither within-group nor between-groups

[d] Force platform indicators are direct measures of balance (e.g., center of pressure behavior, sway, and anterior posterior stability) performed on force platforms (e.g., Biodex Balance System SD)

Table 3. Baseline characteristics of participants in the control and Tai Chi groups (*N*=3247)

Characteristic	*k*	Control Sample (*n*= 1,613)	Tai Chi Sample (*n*= 1,634)
Women in sample (%)	22	64.3 ± 25.9	64.9 ± 25.9
Age (years)	26	72.6 ± 4.9	73.0 ± 5.0
Health Status (%)			
Healthy	11	45.8	47.2
At risk of falling	8	42.2	41.7
Others			
Osteoporosis/Osteopenia	3	4.6	4.7
Frail	1	0.9	0.9
Vision impairment	1	1.2	1.3
Diabetes	1	1.2	1.1
Dizziness	1	1.2	1.3
Unreported	1	2.9	1.9

Note. Data based on 27 interventions. Summary statistics are presented as *M*ean ± standard deviation, unless otherwise stated. *k*= number of observations; *n*= number participants.

Table 4. The Tai Chi exercise prescription and Instructional methods Evaluation tool (TaCIE): Part 1. A Summary of the exercise prescription methods and reporting rate for each item.

Exercise Prescription Items	k	Mean±SD	Range	Reporting Rate *
Frequency (sessions/week)	25	2.8±1.4	1.0, 7.0	92.6%
Time (minutes/session)	23	56.5±14.4	30.0, 90.0	85.2%
Length of Intervention (weeks)	27	19.7±12.7	3.0, 48.0	100.0%

Note. Summary statistics are based on 27 Tai Chi interventions. k= the number of Tai Chi interventions that reported this item. Range represents the Minimum, Maximum values reported for the particular item. SD = standard deviation.
* Reporting rate reflects the percentage of trials that reported the exercise prescription method item (out of 27 total Tai Chi interventions).

Table 5. The Tai Chi exercise prescription and Instructional methods Evaluation tool (TaCIE): Part 2. A summary of the instructional methods and reporting rate for each item.

Instructional Method Items	Definition	k	Mean±SD	Range	Reporting Rate [a]
Items Describing a Tai Chi Routine					
Style [b]	The different lineages that Tai Chi developed into over the years (e.g., Yang, Chen);[49]	13	—		48.1%
Yang (%)		7	53.8		
Sun (%)		4	30.8		
Chen (%)		2	15.4		
Number of Forms	The number of Tai Chi forms were in the routine (e.g., 12 or 24 form-routines)	25	14.6±6.1	5.0, 24.0	92.6%
Name of Forms	The series of movements and postures with a given name (e.g., "wave hands like clouds", "single whip");[66]	4	—		14.8%
Basic Elements of Tai Chi					
Movement Principles	The rules of performing Tai Chi movements (e.g., practitioners should pay attention to exact joint positioning when practicing Tai Chi);[65]	14	—		51.9%
Breathing Techniques	The specific methods of breathing that should be adopted during Tai Chi practice (e.g., continuous diaphragmatic breathing);[66]	8	—		29.6%
Relaxation	The mental state of calm and tranquility;[68]	4	—		14.8%
Items Describing the Delivery of a Tai Chi Practice					
Progression	The method that allows participants to gradually learn and adapt to the Tai Chi routine and improve skills of practicing Tai Chi (e.g., review Tai Chi forms taught previously at the beginning of each class);[105]	6	—		22.2%
Credentials of Instructor [b]	The qualifications of instructors leading Tai Chi practice (e.g., experienced, certified);[69]	21	—		77.8%

Experienced (%)		8	38.1		
Certified/Qualified (%)		7	7.0		
Tai Chi Master (%)		3	3.0		
Others (%) [c]		3	3.0		
Number of Instructors	The number of Tai Chi instructors were that led the intervention;[69]	13	3.1±5.5	1.0, 22.0	48.1%
Unsupervised Practice [b]	Tai Chi practice performed outside of supervised classes (e.g., Tai Chi sessions performed at home);[70]	4	—		14.8%
Encouraged, exercise log used (%)		2	50.0		
Encouraged, no exercise log used (%)		2	50.0		

Note. Summary statistics are based on 27 Tai Chi interventions and presented as Mean±standard deviation (SD), unless otherwise stated. Range represents the Minimum, Maximum values reported for the particular item. — indicates a qualitative or descriptive Tai Chi Instruction Method Item; unable to report Mean±SD. k=the number of Tai Chi trials that reported this item.

[a] Reporting rate is expressed as a percentage of items satisfied out of a total score=27.

[b] For categorical Tai Chi instructional methods items, the subcategories are listed with the frequency (%) they appeared among those trials that reported the item.

[c] Others include: one intervention (3.7%) hired a physical therapist with no clear experience with Tai Chi, and two interventions (7.4%) hired personnel with no evident experience with Tai Chi but did offer them Tai Chi training.

Table 6. Details of exercise prescription methods and instructional methods of 27 interventions based on items from the Tai Chi Ex R_x and Instructional methods Evaluation tool (TaCIE)

	Ex R_x Methods	Instructional Methods: Tai Chi Routine	Instructional Methods: Three Elements	Instructional Methods: Delivery of Tai Chi Exercise and Implementation of Classes			TACIE Reporting Rate (%)	
Author, Year	**Frequency, Time, Length**	**Style, Number of Forms, Name of forms**	**Movement Principles, Breathing Technique, Relaxation**	**Progression**	**Tai Chi Instructors: Credentials and Total Number**	**Unsupervised Practice**	**Ex R_x Items, Instructional Methods,**	**MSQ (%)**
Audette et al., 2006	T: 60	S: Yang	M: X	Teach 1 or 2 forms per session	C: Experienced	X	E: 100.0	58.6
	F: 3	Nu: 10	B: X		Nu: 1		I: 50.0	
	L: 12	Na: X	R: X				T: 61.5	
Chen et al., 2012	T: 90	S: Yang	M: Yes	X	C: X	X	E: 100.0	44.8
	F: 3	Nu: 8	B: X		Nu: X		I: 30.0	
	L: 16	Na: X	R: X				T: 46.2	
Chyu et al., 2010	T: 60	S: Yang	M: X	X	C: X	X	E: 100.0	65.5
	F: 3	Nu: 24	B: Yes		Nu: X		I: 40.0	
	L: 24	Na: X	R: Yes				T: 53.8	
Frye et al., 2007	T: 60	S: X	M: X	Practice single form until participants master	C: Experienced	X	E: 100.0	79.3
	F: 1	Nu: 10	B: Yes		Nu: X		I: 60.0	

	L:	12	Na:	Yes	R:	Yes					T:	69.2	
Gatt and Marjorie, 2006	T:	90	S:	X	M:	Yes	(1) movement principles; (2) upper body movements; (3) lower body movements; (4) connect all forms	C:	Experienced	X	E:	100.0	55.2
	F:	5	Nu:	15	B:	X		Nu:	1		I:	60.0	
	L:	3	Na:	Yes	R:	X					T:	69.2	
Hass et al., 2004	T:	X	S:	X	M:	Yes	X	C:	X	X	E:	66.7	62.1
	F:	2	Nu:	8	B:	X		Nu:	X		I:	20.0	
	L:	48	Na:	X	R:	X					T:	30.8	
Huang et al., 2010	T:	40	S:	X	M:	X	X	C:	Qualified	X	E:	100.0	55.2
	F:	3	Nu:	13	B:	X		Nu:	2		I:	30.0	
	L:	20	Na:	X	R:	X					T:	46.2	
Kim, 2009	T:	60	S:	X	M:	Yes	X	C:	Experienced	X	E:	100	58.6
	F:	3	Nu:	10	B:	Yes		Nu:	2		I:	40.0	
	L:	12	Na:	X	R:	X					T:	53.8	

Kim, Han, and Cho, 2009	T:	60	S:	X	M:	Yes	X	C:	Tai Chi master	X	E:	100.0	62.1
	F:	3	Nu:	12	B:	X		Nu:	1		I:	50.0	
	L:	12	Na:	X	R:	X					T:	61.5	
Lalard et al., 2010	T:	30	S:	X	M:	Yes	X	C:	Physical Therapist	X	E:	100.0	37.9
	F:	2	Nu:	10	B:	X		Nu:	X		I:	30.0	
	L:	12	Na:	X	R:	X					T:	46.2	
Li et al., 2005	T:	60	S:	Yang	M:	Yes	X	C:	Experienced	X	E:	100.0	82.8
	F:	3	Nu:	24	B:	Yes		Nu:	X		I:	50.0	
	L:	26	Na:	X	R:	X					T:	61.5	
Li, Xu, and Hong, 2008	T:	X	S:	X	M:	X	X	C:	Qualified	X	E:	33.3	55.2
	F:	X	Nu:	24	B:	X		Nu:	1		I:	30.0	
	L:	16	Na:	X	R:	X					T:	30.8	
Logghe et al., 2009	T:	60	S:	Yang	M:	X	X	C:	Professional	Encouraged: 2×15 minutes/ week; no	E:	100.0	58.6

										record of actual time			
	F:	2	Nu:	10	B:	X		Nu:	4		I:	50.0	
	L:	13	Na:	X	R:	X					T:	61.5	
Maciaszek et al., 2007	T:	45	S:	X	M:	Yes	X	C:	Certified	X	E:	100.0	44.8
	F:	2	Nu:	5	B:	X		Nu:	X		I:	30.0	
	L:	18	Na:	X	R:	X					T:	46.2	
Maciaszek and Osinski, 2012	T:	45	S:	X	M:	Yes	X	C:	Certified	X	E:	100.0	44.8
	F:	2	Nu:	24	B:	X		Nu:	X		I:	30.0	
	L:	18	Na:	X	R:	X					T:	46.2	
Ni et al., 2014	T:	60	S:	Chen	M:	Yes	X	C:	Tai Chi master	X	E:	100.0	64.5
	F:	2	Nu:	18	B:	X		Nu:	1		I:	60.0	
	L:	12	Na:	Yes	R:	X					T:	69.2	
Pluchino et al., 2012	T:	60	S:	Sun	M:	Yes	X	C:	Certified	X	E:	100.0	62.1
	F:	2	Nu:	12	B:	X		Nu:	1		I:	50.0	

	L:	8	Na:	X	R:	X					T:	61.5	
Song et al., 2014	T:	40	S:	Chen	M:	X	X	C:	X	X	E:	100.0	51.6
	F:	6	Nu:	X	B:	X		Nu:	X		I:	10.0	
	L:	48	Na:	X	R:	X					T:	30.8	
Song et al., 2003	T:	X	S:	Sun	M:	X	2 weeks teaching phase at beginning	C:	Training pre-intervention	Encouraged; time recorded with exercise log	E:	33.3	51.7
	F:	X	Nu:	12	B:	Yes		Nu:	X		I:	70.0	
	L:	12	Na:	Yes	R:	Yes					T:	61.5	
Taylor et al., 2012 (group 1)	T:	60	S:	Sun	M:	X	X	C:	Experienced + training	X	E:	100.0	86.2
	F:	1	Nu:	10	B:	X		Nu:	X		I:	30.0	
	L:	20	Na:	X	R:	X					T:	46.2	
Taylor et al., 2012 (group 2)	T:	60	S:	Sun	M:	X	X	C:	Experienced + training	X	E:	100.0	86.2
	F:	2	Nu:	10	B:	X		Nu:	X		I:	30.0	
	L:	20	Na:	X	R:	X					T:	46.2	

Taylor-Piliae et al., 2010	T:	45	S:	Yang	M:	Yes	Teach 1-2 forms per session	C:	Tai Chi master	Encouraged; time not recorded	E:	100.0	82.8
	F:	0-24/ 25-48 weeks=5/ 4 days	Nu:	18	B:	Yes		Nu:	1		I:	90.0	
	L:	48	Na:	X	R:	1					T:	92.3	
Tsang et al., 2007	T:	60	S:	X	M:	X	X	C:	Training	X	E:	100.0	65.5
	F:	2	Nu:	12	B:	Yes		Nu:	1		I:	40.0	
	L:	16	Na:	X	R:	X					T:	53.8	
Voukelatos et al., 2007	T:	60	S:	X	M:	X	X	C:	Experienced	X	E:	100.0	75.9
	F:	1	Nu:	X	B:	X		Nu:	22		I:	20.0	
	L:	16	Na:	X	R:	X					T:	38.5	
Woo et al., 2007	T:	X	S:	Yang	M:	X	X	C:	X	X	E:	66.7	43.3
	F:	3	Nu:	24	B:	X		Nu:	X		I:	20.0	
	L:	48	Na:	X	R:	X					T:	30.8	
Wolf et al., 1997	T:	30	S:	X	M:	Yes	2 sessions/week, teach form in first session; practice	C:	X	X	E:	100.0	55.2

							form in second session						
	F:	2	Nu:	10	B:	X		Nu:	X		I:	30.0	
	L:	15	Na:	X	R:	X					T:	46.2	
Zhang et al., 2006	T:	60	S:	X	M:	Yes	X	C:	Experienced	Encouraged: shorter routine designed for home practice; time recorded with exercise log.	E:	100.0	65.5
	F:	7	Nu:	24	B:	Yes		Nu:	2		I:	60.0	
	L:	8	Na:	X	R:	X					T:	69.2	

Note. X indicates information regarding this item was not reported in the trial.
Abbr. Ex R_x = exercise prescription.

Table 7. Correlations of balance outcomes and other dimensions across the 27 Tai Chi interventions.

Variable		Mean	SD	1	2	3	4	5	6	7	8
1.	Balance outcomes [a,b]	19.0	70.4								
2.	Total methodological study quality (%)	62.7	13.0	-0.08							
3.	Ex R_x methods items, reporting rate (%)	92.6	19.2	-0.11	0.04						
4.	Instructional methods items, reporting rate (%)	41.1	18.0	0.22	0.33*	0.03					
5.	Frequency (sessions/week)	2.8	1.5	0.25	0.14	0.06	0.25				
6.	Time (minutes/session)	56.3	14.7	0.22	0.18	0.66	0.26	0.10			
7.	Length of intervention (weeks)	19.7	12.9	-0.04	0.19	-0.17	-0.27	0.19	-0.38*		
8.	Emphasize movement principles (yes/no) [b]	14.0	51.9	0.35*	-0.32	0.28	0.23	0.20	0.02	-0.12	
9.	Disclose name of Tai Chi forms [b]	4.0	14.8	0.27	0.11	-0.20	0.50**	-0.03	0.37*	-0.33*	-0.02

Note. Summary statistics are based on 27 Tai Chi interventions and are presented as Mean ± standard deviation (SD), unless otherwise stated.

Abbr. Ex R_x= exercise prescription.

[a] Balance outcomes were coded as 1 (= Yes) when authors reported significant improvements in any measure of balance for the Tai Chi group post- versus pre-intervention (i.e., within-group) or post-intervention versus control. If no significant improvements were reported by the authors for Tai Chi groups, balance outcomes were coded as -1 (= No)

[b] For categorical items, number of observations and frequency (%) they appeared among all 27 interventions are listed.

**P < 0.05. *P ≤ 0.10.

Chapter 3-B. Tai Chi as Antihypertensive Lifestyle Therapy: A Systematic Review and Meta-Analysis

Yin Wu, MA[a,b], Blair T. Johnson, PhD[b,c], Shiqi Chen, BS[d], Yiyang Chen, BS[e], Jill Livingston, MLS, and Linda S. Pescatello, PhD[a,b]

[a]Department of Kinesiology, University of Connecticut, Storrs, CT, USA

[b]Institute for Collaboration on Health, Intervention, and Policy, University of Connecticut, Storrs, CT, USA

[c]Department of Psychological Sciences, University of Connecticut, Storrs, CT, USA

[d]Department of Kinesiology, University of Michigan, Ann Arbor, MI, USA

[e]School of Kinesiology, Shanghai University of Sport, Shanghai, China

[f]Homer Babbidge Library, Health Sciences, University of Connecticut, Storrs, CT, USA

Research Support: A sub-contract from U.S. PHS grant 5U24AG052175

University of Connecticut Center for Excellence in Teaching and Learning

Correspondence: Yin Wu, M.A.

Department of Kinesiology, 2095 Hillside Road Unit 1110

University of Connecticut, Storrs, CT 06269-1110, USA.

Telephone: (860) 929-6382 Fax: (860) 486-1123 Email: yin.2.wu@uconn.edu

Abstract

Due to limited evidence professional health organizations are reluctant to recommend Tai Chi to treat hypertension. We conducted a systematic review and meta-analysis to examine the efficacy of Tai Chi as antihypertensive lifestyle therapy. Tai Chi interventions published in English and Chinese were included when they involved healthy adults, reported pre-and post-intervention blood pressure (BP), and had a non-exercise/non-diet control group. We systematically searched 11 electronic databases through August 1, 2018, yielding 31 qualifying controlled trials. We: 1) evaluated the risk of bias and methodological study quality; 2) performed meta-regression analysis following random-effects assumptions; and 3) generated additive models representing the largest possible clinically relevant BP reductions. On average, participants (N=3,223) were middle-aged (56.6±15.1 years) adults with prehypertension (systolic BP [SBP] 136.9±15.2/diastolic BP [DBP] 83.4±8.7 mmHg). Tai Chi was practiced 4.0±1.4 sessions/week for 54.0±10.6 minutes/session for 22.3±20.2 weeks. Overall, Tai Chi elicited moderate to large reductions in SBP (d_+=-0.75, 95%*CI*s: -0.97, -0.53; -8.7 mmHg) and DBP (d_+=-0.53, 95%*CI*s: -0.71, -0.34; -4.7 mmHg) compared to control (*P*s<.001). Controlling for publication bias among samples with hypertension, Tai Chi interventions published in English elicited SBP reductions of 10 mmHg and DBP of 4 mmHg, half the magnitude of trials published in Chinese with SBP reductions of 19 mmHg and DBP reductions of 9 mmHg. Our results indicate that Tai Chi is viable antihypertensive lifestyle therapy that produces BP reductions that rival or exceed the antihypertensive effects of aerobic exercise of 5-8 mmHg in both the English and Chinese literature. Further investigation is needed to explain the discrepancy in the magnitude of the antihypertensive effects between Tai Chi trials published in English and Chinese.

Introduction

Hypertension is the most common cardiovascular disease (CVD) risk factor, affecting nearly 50% of adults in the United States (US) according to the 2017 American College of Cardiology (ACC) and American Heart Association (AHA) Guidelines.[1] The ACC/AHA recommend aerobic exercise as antihypertensive lifestyle therapy because it lowers blood pressure (BP) 5-8 mmHg.[1,2] Accordingly, adults with hypertension are encouraged to engage in moderate to vigorous intensity aerobic exercise on most, preferably, all days of the week.[1] Unfortunately, most adults (72%) with hypertension do not adhere to these exercise recommendations for hypertension.[3]

Tai Chi is a safe, low impact, enjoyable, and inexpensive form of exercise accessible to individuals who, for various reasons, cannot or choose not to engage in aerobic exercise.[4,5,6] Tai Chi is a form of mind-body exercise that employs rhythmic physical motions, while emphasizing relaxation and breathing techniques. Tai Chi has numerous health benefits, with BP being one of the top health outcomes studied in this literature.[4,7,8] In fact, Tai Chi has been reported to elicit systolic BP (SBP) reductions as large as ~17-19 mmHg and diastolic BP (DBP) reductions as large as ~11-13 mmHg in primary level intervention Tai Chi studies published in English and Chinese.[9-11] Yet, due to limited evidence professional committees and organizations such as the 2018 Physical Activity Guidelines Advisory Committee and ACC/AHA are reluctant to recommend Tai Chi as an alternative antihypertensive lifestyle therapy to aerobic exercise which is regarded as the standard of care.[1,12,13]

To our best knowledge, three prior meta-analyses published in English have quantified the BP lowering effects of Tai Chi. Two of these meta-analyses reported clinically meaningful unstandardized mean effect sizes of -12.4 to -15.2 mmHg for SBP, and -4.1 to -6.0 mmHg for

DBP;[14,15] while the third meta-analysis reported medium to large standardized mean effect sizes of -0.93 for SBP and -0.54 for DBP.[16] Despite these encouraging findings, these meta-analyses had limitations including: 1) two of the three meta-analyses combined samples of various BP status, rendering it impossible to distinguish among adults having normal BP from those with hypertension;[15,16] 2) all three meta-analyses are dated (i.e., published in 2015 or earlier); 3) all included small samples (k=9 to 12; N=536 to 832); and 4) the statistical procedures used for the effect size calculations were not disclosed. Furthermore, despite high heterogeneity (I^2 ranged from 74% to 90% when disclosed),[15,16] moderator analyses were not performed to investigate if any study (e.g., trial location), sample (e.g., baseline BP status), or Tai Chi intervention (e.g., frequency) characteristics influenced BP response to Tai Chi.[14-16]

To address gaps in the literature, we conducted the largest meta-analysis to date to examine the efficacy of Tai Chi as antihypertensive lifestyle therapy, while examining moderators of the BP response to Tai Chi with meta-regression analysis, a contemporary statistical technique that can examine multiple moderators at the same time.[17-19,20] In addition, we investigated which combination of study, sample, and Tai Chi intervention characteristics generated the largest possible BP reductions with additive regression models to provide insights into the clinical utility of Tai Chi as antihypertensive lifestyle therapy.

Methods

Selection Criteria

According to five a priori inclusion criteria, trials were eligible if they: 1) enrolled adults ≥18 years of any BP status who were otherwise healthy; 2) explicitly stated that the intervention was Tai Chi；3) included a non-exercise/non-diet control group; 4) reported BP pre- and post-intervention for the Tai Chi and control groups; and 5) were published in peer-reviewed language journals in either English or Chinese. Trials were excluded if they: 1) included samples with chronic disease (e.g., CVD, diabetes mellitus, cancer); 2) prescribed drug/supplements, dietary interventions, or another type of exercise in addition to Tai Chi; or 2) involved a single Tai Chi session (i.e., an acute intervention).

Search Strategy

Aided by a medical librarian (J.L.), we systematically searched six electronic databases in English and five electronic databases in Chinese from their inception until July 31, 2018 (see online supplemental material Data S1). Potential reports were screened in duplicate by trained coders (Y.W, S.C., C.Y), first by title and abstract and then by full-text. Reference lists of included trials, relevant meta-analyses, and reviews were manually searched for additional reports.

Data Extraction and Coded Variables

Data were extracted using our standardized coding form and coder manual[21,22] adapted according to a previously published scale. This scale was specially designed to evaluate the *F*requency, *I*ntensity, and *T*ime (or the *FIT* principle of exercise prescription) and instructional methods (e.g., breathing techniques, credentials of the instructors) of Tai Chi interventions aimed at improving balance for older adults.[23] Three trained coders (Y.W., S.C., Y.C.) independently extracted and entered the study information for all included trials with high reliability (mean Cohen's k=0.85 and Pearson's r=0.88). All disagreements were resolved through discussion.

We coded characteristics related to the study (e.g., trial location, publishing language), sample (e.g., baseline BP, body mass index [BMI]), and Tai Chi intervention (i.e., the *FIT* and instructional methods). Of note, in our meta-analysis, we followed the Seventh Report of the Joint National Committee (JNC7) definitions of hypertension (i.e., hypertension, prehypertension, and normal BP) because the majority of research on Tai Chi and hypertension was conducted before release of the 2017 ACC/AHA guidelines. Methodological study quality was assessed using an augmented version of the Downs and Black checklist (27 items) that was scored as the percentage of items satisfied out of a possible 32-point total.[24] Overall methodological study quality scores were grouped into: low (≤16 points, <50%), moderate (>16 to 25 points, 50-79%), or high (>25 points, ≥80%).[25,26] Risk of bias was assessed using the Cochrane risk of bias tool.[27] Under the category of "other bias", we coded the time between the last session of Tai Chi and the post-intervention BP measurement to account for the BP effects of acute exercise (i.e., postexercise hypotension);[20,28] and detraining as the BP benefits of exercise dissipate rapidly upon the cessation of training.[29]

Effect Size Calculations

The standardized mean difference effect size (*d*) quantified the effectiveness of Tai Chi as an antihypertensive therapy, and was calculated as the mean difference in resting SBP or DBP between the Tai Chi and control groups post- versus pre-intervention divided by the pooled standard deviation (*SD*), correcting for small sample size bias and baseline differences between the groups.[30,31] Because we observed a large variation of the distribution of SBP (*SD* ranged from 3.3 to 25.3)[32,33] and DBP (*SD* ranged from 3.6 to 17.1)[11,34] across the included trials, we chose to use standardized effect sizes which are more robust with less bias and have better efficiency compared to unstandardized effect sizes under many statistical circumstances.[35] Negative *d* values indicate Tai Chi reduced BP more post- versus pre-intervention compared to the control group. When reaching statistical significance ($P<.05$), *ds* were interpreted as insufficient (0 to -0.19), small (-0.20 to -0.49), medium (-0.50 to -0.79), and large (≥-0.80) BP reductions.[36] Inconsistencies in *d* values were assessed with the *Q* statistic, which we transformed into the I^2 statistic and its confidence intervals (95% *CIs*).[37,38] I^2 values range from low (0%) to high (100%) heterogeneity.

Moderator Analyses

We examined characteristics related to the study, sample, and Tai Chi interventions as moderators of BP response to Tai Chi. Weighted regression models with maximum likelihood estimation of the random-effects weights (i.e., the inverse of the variance for each *d*) were used to explain variability in *ds* for SBP and DBP. In multiple moderator models, we examined significant or trending moderators ($P \leq .10$) from bivariate meta-regression analyses[39] in conjunction with the model coefficients and R^2 values (i.e., between-study variance explained by a covariate) to determine the influence of individual moderators on the BP response to Tai Chi.[40] The moving constant technique[41] estimated the magnitude of the weighted mean effect size (d_+) and its 95% *CI* at different levels of interest for individual moderators, while statistically controlling for the presence of other moderators held constant at their mean levels and arrived at an estimate, or predicted d_+, denoted as $\hat{d}_+$.[41]

For SBP and DBP, additive regression models were generated from the final multiple-moderator models that represented the greatest potential antihypertensive benefit from Tai Chi. Individual moderators were assessed within the same model at the level that yielded the greatest BP reduction (i.e., $\hat{d}_+$ and 95% *CIs*). To facilitate clinical interpretation for each moderator dimension and level of interest, we back-converted the standardized estimate (i.e., $\hat{d}_+$) into mmHg of BP change by multiplying the $\hat{d}_+$ by the *SD* of baseline SBP (i.e., 15) and the *SD* of baseline DBP (i.e., 9) calculated on all included Tai Chi trials.[22]

Publication Bias

We evaluated the potential for publication or other reporting biases in both SBP and DBP *d*s by: 1) visually examining the distribution and asymmetry of funnel plots;[42] and 2) using Begg's[43] and Egger's[44] tests, in addition to performing the Precision-Effect Test and Precision-Effect Estimate with Standard Error analysis (PET-PEESE) to determine if potential publication bias needed to be controlled by including the standard error (*SE*) of the BP response to Tai Chi in the multiple-moderator models for SBP and DBP.[45]

Sensitivity Analyses

Of note, because there were more non-randomized controlled trials (NRCT; 54.8%, *k*=17) than randomized controlled trials (RCT; 45.2%, *k*=14) we did not restrict our sample to RCTs. We performed sensitivity analyses to compare the *d*s from RCTs and NRCTs.[46] Affirming the decision to combine RCTs and NRCTs for analyses, there was no difference between the mean effect sizes of RCTs and NRCTs for SBP or DBP (*P*s>.35). In addition, we paired study design with other variables included in the final multiple-moderator models (see Tables 3 and 4), and examined as competing moderators (e.g., RCT vs. NRCT and baseline BP status) of the BP response to Tai Chi. Study design was the weaker, non-significant moderator when examined in tandem with the baseline SBP (*P*=.72), publishing language (*P*=.16), or the *SE* of the SBP response to Tai Chi (*P*=.31) in the SBP multiple-moderator model; and with baseline DBP (*P*=.59) or publishing language (*P*=.42) in the DBP multiple-moderator model. These results reinforced our decision to combine RCTs and NRCTs in our analysis.

Statistical Computing

Analyses were performed using Stata version 14.1 (Stata Corp, College Station, TX) [47] with macros for meta-analysis,[39,48] and incorporated random-effects assumptions. Stata commands are listed in Data S2. Descriptive statistics are reported as the *M*ean±*SD* unless stated otherwise. Two-sided significance level was $P<.05$.

Results

We identified 31 controlled Tai Chi trials that satisfied the inclusion criteria (see Figure 1).[9-11,32-34,49-73]

[INSERT FIGURE 1 HERE]

Study Characteristics

Tai Chi trials were published between 1997 and 2018 (2011±5) in English (59.1%, k=18) and Chinese (40.9%, k=13) language journals and consisted of 20 to 300 (n=104±74) participants each. Trails were RCTs (45.2%, k=14) or NRCTs (54.8%, k=17), and most examined BP as the primary outcome (77.4%, k=24). On average, the included Tai Chi trials achieved "moderate" methodological study quality on the augmented Downs and Black Checklist (50.1%±16.3%),[74] despite widely varying scores (25.8% to 87.1%). The interventions also exhibited high levels of risk of bias based on the Cochrane Risk of Bias Tool.[27] In particular, most of the interventions did not report methods to conceal group allocation after randomization (78.6%), or to blind investigators to the group allocation (77.4%). In addition, none of the Tai Chi trials specified the time between the post-intervention BP measurements and the last Tai Chi session.

Sample Characteristics

Baseline sample characteristics were similar between the Tai Chi (n=1,654) and control (n=1,569) groups (*P*s>.05) (Data S3). On average, participants (N=3,223) were middle-aged (56.6±15.1 years) adults with prehypertension (SBP 136.9±15.2/DBP 83.4±8.7 mmHg), and predominantly women (69.5±21.6%). Among our sample, based on baseline BP values and use of BP medications,[75] 16 trials (51.6%) involved samples (*n*=1750) with hypertension (SBP 148.4±8.9/DBP 88.3±8.3 mmHg). Meanwhile, 10 trials (32.3%) involved samples (*n*=854) with prehypertension (SBP 130.4±5.6/DBP 80.9±3.6 mmHg), and five trials (16.1%) involved samples (*n*=619) with normal BP (SBP 113.2±5.4/DBP 72.5±3.9 mmHg). Eight trials (25.8%) provided information regarding medication use. Of these, five trials reported that no participants were taking BP medications, while all participants had hypertension.[34,49,61,63,66] Two trials disclosed the percentage of participants that were taking specific categories of BP medications, with calcium channel blockers being the most popular category (i.e., 52-55%).[59,65] In addition, one trial reported that all of its participants had dyslipidemia and were taking statins.[56]

Tai Chi Intervention Characteristics

Table 1 provides the details of the Tai Chi intervention characteristics. Tai Chi was practiced, on average, 4.0±1.4 sessions/week for 54.0±10.6 minutes/session for 22.3±20.2 weeks. Tai Chi interventions included, on average, 30.4±25.4 forms following Yang (48.4%, *k*=15), Chen (3.2%, *k*=1)[49] or undisclosed (48.4%, *k*=15) styles; however, less than one third of the trials disclosed the names of the Tai Chi forms (25.8%, *k*=8) or adopted progression methods (see Table 1) to facilitate the learning of Tai Chi practice (32.3%, *k*=10). Few trials reported emphasis on the three fundamental elements of Tai Chi practice, including movement principles (12.9%, *k*=4), breathing techniques (19.4%, *k*=6), or relaxation (9.7%, *k*=3). Only one trial (3.2%) reported that all three elements were emphasized.[34]

Among included Tai Chi trials, only one (3.2%) disclosed the average heart rate (HR) during Tai Chi practice (i.e., 63.7% of the aged predicted maximum heart rate [HR_{max}]).[76] Meanwhile, 10 trials (32.3%) monitored and instructed participants to exercise at various HR ranges that ranged from 40 to 85% of the age predicted HR_{max}, or between 110 to 130 beats/minute, but they did not disclose the actual HR values. One trial stated that HR was recorded during Tai Chi exercise but provided no further information.[71] All trials (100.0%, *k*=31) included supervised Tai Chi exercise; however, only about half of the trials disclosed the number of instructors (45.2%, *k*=14) or the credentials (58.1%, *k*=18) of the instructors (see Table 1). In addition, five trials (16.1%, *k*=5) recommended unsupervised home practice without disclosing the actual time spent practicing.

[INSERT TABLE 1 HERE]

Resting Blood Pressure Assessment

Most trials (67.7%, *k*=21) reported the BP assessment instrument used. These included automated/digital units (32.3%, *k*=10) or manual sphygmomanometers (35.5%, *k*=11). About one third of the trials (32.3%, *k*=10) reported the body position during the BP assessments, which included seated (29.0%, *k*=9) or supine (3.2%, *k*=1) positions. Yet, 11 trials (35.5%) did not report any details of the resting BP assessment procedures.

Tai Chi as Stand-Alone Antihypertensive Therapy

Overall, Tai Chi elicited moderate to large reductions in SBP (d_+=-0.75, 95%*CI*s: -0.97, -0.53; -8.7 mmHg) and DBP (d_+=-0.53, 95%*CI*s: -0.71, -0.34; -4.7 mmHg) compared to controls (*P*s<.001) (Data S4); however, the standardized effect sizes for SBP (I^2=88.3%, 95%*CI*s: 84.6%, 91.2%) and DBP (I^2=83.9%, 95%*CI*s: 78.1%, 88.2%) lacked homogeneity. In addition, the mean effect sizes of RCTs and NRCTs were similar for SBP (-0.74 vs. -0.77, *P*=.92) and DBP (-0.44 vs. -0.61, *P*=.35), which supported our decision to combine RCTs with NRTCs in our analysis.

Publication Bias

The funnel plot (Data S4), Begg's test, and Egger's test all suggested that there was significant publication bias for the SBP response to Tai Chi (Begg's test: z=-2.97, P=.003; Egger's test: t=-3.91, P=.001).[42,43,44] Meanwhile, both the funnel plot and Egger's test suggested that there was significant publication bias for the DBP response to Tai Chi (t=-2.37, P=.03), but the Begg's test did not (z=-1.41, P=.16).[42,43,44] Following the PET-PEESE[45] analysis, potential publication bias was apparent (P=.02) only for the SBP response to Tai Chi; thus, publication basis was controlled for in the multiple-moderator model of SBP.

Multiple Moderator Models

When controlling for publication bias, SBP reductions were greater among Tai Chi trials published in Chinese (16.7 mmHg) than English (8.4 mmHg, P=.005) (Table 2). In addition, SBP was reduced more in samples with the highest baseline SBP (P=.04): 14.4 mmHg for samples with hypertension; 11.3 mmHg for samples with prehypertension; and 8.3 mmHg for samples with normal BP. Collectively, these moderators accounted for 45.3% of the variance in the SBP response to Tai Chi. The additive regression model (Table 2) revealed that controlling for publication bias among samples with hypertension, Tai Chi trials published in Chinese elicited SBP reductions of 19 mmHg, nearly twice the magnitude of the SBP reductions of 10 mmHg for Tai Chi trials published in English.

[INSERT TABLE 2 HERE]

DBP reductions were greater among Tai Chi trials published in Chinese (7.7 mmHg) than those published in English (2.9 mmHg, P<.001) (Table 3). In addition, DBP was reduced more in samples with the highest baseline DBP (P<.001): 6.4 mmHg for samples with hypertension; 4.8 mmHg for samples with prehypertension; and 2.8 mmHg for samples with normal BP. Collectively, these moderators accounted for 65.9% of the variance in the DBP response to Tai

Chi. The additive regression model (Table 3) revealed that, among samples with hypertension, Tai Chi interventions published in Chinese elicited DBP reduction of 9 mmHg, nearly twice the magnitude of the DBP reductions of 4 mmHg for Tai Chi trials published in English.

[INSERT TABLE 3 HERE]

Discussion

Our meta-analysis aimed to examine the efficacy of Tai Chi as antihypertensive lifestyle therapy with the largest sample size examined to date, and moderators of the BP response to Tai Chi. We found, on average, that Tai Chi practiced ~4 sessions/week for ~60 minutes/session for ~22 weeks produced BP reductions of ~5-9 mmHg. Our novel finding after controlling for publication bias among samples with hypertension was that Tai Chi trials published in English elicited SBP reductions of 10 mmHg and DBP reductions of 4 mmHg; while Tai Chi trials published in Chinese elicited SBP reductions of 19 mmHg and DBP reductions of 10 mmHg. The magnitude of these BP reductions rivals or even doubles those reported for aerobic exercise training (i.e., ~5-8 mmHg). Even the more conservative magnitude of BP reductions reported in the English literature would reduce the risk of heart disease by ~22% and stroke by ~ 41%,[77] and may lower the BP of adults with hypertension into normotensive ranges.[78,79] These large and clinically meaningful BP reductions support the use of Tai Chi as an alternative to aerobic exercise as antihypertensive lifestyle therapy based on either the English or Chinese literature.

Currently, aerobic exercise is the primary exercise modality recommended to prevent, treat, and control hypertension.[79] However, less than a third (28%) of adults with high BP adhere to the current aerobic exercise recommendations for hypertension.[3] Therefore, in order to improve exercise adherence other exercise options with comparable BP benefits such as we recently reported with yoga[80] and now Tai Chi hold promise as viable alternatives to aerobic exercise, especially when people are unwilling or unable to engage in aerobic exercise to lower their high BP. Indeed, adults with hypertension may show better adherence to Tai Chi than aerobic exercise because it is a safe, low impact, enjoyable, and inexpensive form of exercise that requires minimum equipment and space.[4,5-7,81] Tai Chi also provides various physiological (e.g., managing arthritis symptoms especially pain) and psychological health benefits (e.g., alleviating fear of falling, reducing stress), some of which (e.g., improving balance) are distinct from more traditional forms of exercise.[8,82]

Our meta-analysis also identified several moderators of BP response to Tai Chi that warrant further comment. Our most novel finding was that when controlling for other moderators, the magnitude of BP reductions was significantly larger among trials published in Chinese than trials published in English for both SBP (~17 vs. ~8 mmHg) and DBP (~8 vs. ~3 mmHg). This finding suggests that it would not be appropriate to use one mean effect size calculation on trials combined from the English and Chinese literature to represent the efficacy of Tai Chi as antihypertensive lifestyle therapy,[83,84] as all three previous meta-analyses did.[14-16] As a result, in the additive regression models, we estimated the greatest potential BP reductions separately for Tai Chi trials published in Chinese and English (See Tables 2 and 3). This finding emphasizes that further investigation is needed to explain the large discrepancies in the magnitude of the antihypertensive effects of Tai Chi between trials published in Chinese and English.

Accordingly, we compared differences in the samples, Tai Chi interventions, and study characteristics (see Table 4) between Tai Chi trials published in Chinese and English. In relation to sample characteristics, the sole difference we found was that trials published in Chinese had samples with higher DBP at baseline (*P*=.03), which may have contributed to the greater DBP reductions reported. Overall, we did not identify any differences in Tai Chi intervention characteristics that may have contributed to the greater BP reductions reported in trials published in Chinese than English. In relation to the study characteristics, Tai Chi trials published in Chinese differed from English language trials in that they: 1) tended to have smaller sample sizes (*P*=.052); 2) had lower methodological study quality evaluated by the Downs and Black Checklist (*P*<.001);[24] 3) were less likely to adopt a RCT design (*P*=.04); and 4) had greater publication bias in relation to SBP (indicated by the SE of the SBP response to Tai Chi, *P*=.048), and tended to have greater publication bias in relation to DBP (indicated by the SE of the DBP response to Tai Chi, *P*=.06). These findings indicate that Chinese language journals are more likely to publish Tai Chi trials showing significant BP reductions with noticeable limitations in their study methodological methods. The limitations likely contributed to the overall greater BP reductions reported in Tai Chi trials published in Chinese than English.[84,85] We also acknowledge that there could be other factors that contributed to the greater BP reductions reported in Tai Chi trials published in Chinese, such as participants' expectations and Tai Chi instructors' teaching skills;[86] however, none of these items were adequately reported to allow quantitative comparisons.

The second moderator we identified was the baseline BP status that when controlling for other moderators, BP reductions were the largest among interventions that involved samples with hypertension (SBP ~14/DBP ~6 mmHg), prehypertension (SBP ~11/DBP ~5 mmHg), and normal BP (SBP ~8/DBP ~3 mmHg).[75] This finding is consistent with the law of initial values,[28] that the magnitude of the response is directly related to the initial level of the health outcome being measured.

It should be noted that overall the included Tai Chi trials were of moderate methodological study quality (i.e., 50.1% of items satisfied on the Downs and Black Checklist[24]). Following the Grading of Recommendations, Assessment, Development, and Evaluation Approach (GRADE),[87,88] we recommend readers place moderate certainty in our findings because included Tai Chi trials exhibited: 1) a high risk of bias evaluated by the Cochrane Risk of Bias Tool; 2) high levels of heterogeneity (i.e., I^2 ranged from 83.9% to 88.3%); and 3) some evidence of publication bias, especially in relation to SBP. In addition, we recommend readers place more certainty in Tai Chi trials published in English than Chinese for the differences in study characteristics discussed previously (see Table 4).

Although our multiple moderator models explained a clinically meaningful portion of the variance of the SBP (45.3%) and DBP (65.9%) responses to Tai Chi, it was unsurprising that these models left a large amount of variance in effects unexplained. We evaluated 18 other potential sources of influence and found that these factors were unrelated to the BP responses to Tai Chi among included trials (Data S5). It remains possible that some authors of the included Tai Chi trials inadvertently omitted details of their studies due to space limitations or other unknown reasons, which limited our ability to extract such information and perform analyses. We also acknowledge that additional unidentified moderators may exist in this literature. For example, several potentially important moderators could not be investigated or did not reach statistical significance because they were not adequately disclosed, such as the intensity of Tai Chi practice (3.2% reported) and the inclusion of relaxation (9.7% reported) or breathing techniques (22.7% reported) during Tai Chi practice. Lastly, another limitation of our meta-analysis was that we did not search for the grey literature or Tai Chi trials published in languages other than Chinese and English.

Our meta-analysis also had several strengths. First, we performed meta-regression analysis allowing us to examine multiple moderators of the BP responses to Tai Chi simultaneously.[17-19] Secondly, the use of contemporary statistical strategies, in particular the moving constant technique,[41] allowed us to estimate the magnitude of BP reduction at different clinically significant levels of the individual moderators (see Tables 2 and 3). Last, although all previous meta-analyses that examined the BP benefits of Tai Chi have included trials published in both Chinese and English, our study was the first that examined publishing language as a moderator of BP response to Tai Chi. Importantly, our results suggest that more confidence should be placed in the Tai Chi trials published in English due to the more noticeable limitations in study methodological methods and greater publication bias in Tai Chi trials published in Chinese.

In conclusion, our new and noteworthy findings are that Tai Chi interventions published in English elicited SBP reductions of 10 mmHg and DBP of 4 mmHg, while trials published in Chinese elicited SBP reductions of 19 mmHg and DBP reductions of 9 mmHg among samples with hypertension. Therefore, Tai Chi may elicit BP reductions equal to or greater in magnitude than the BP reductions resulting from aerobic exercise indicating that Tai Chi may be a viable antihypertensive lifestyle therapeutic exercise option to prevent, treat, and control hypertension. Nonetheless, whether Tai Chi is indeed as effective as aerobic exercise as antihypertensive therapy still should be confirmed in future RCTs that directly compare the BP lowering effects of Tai Chi and aerobic exercise among adults with hypertension, [89,90] to explain the discrepancies between trials published in Chinese and English literature.

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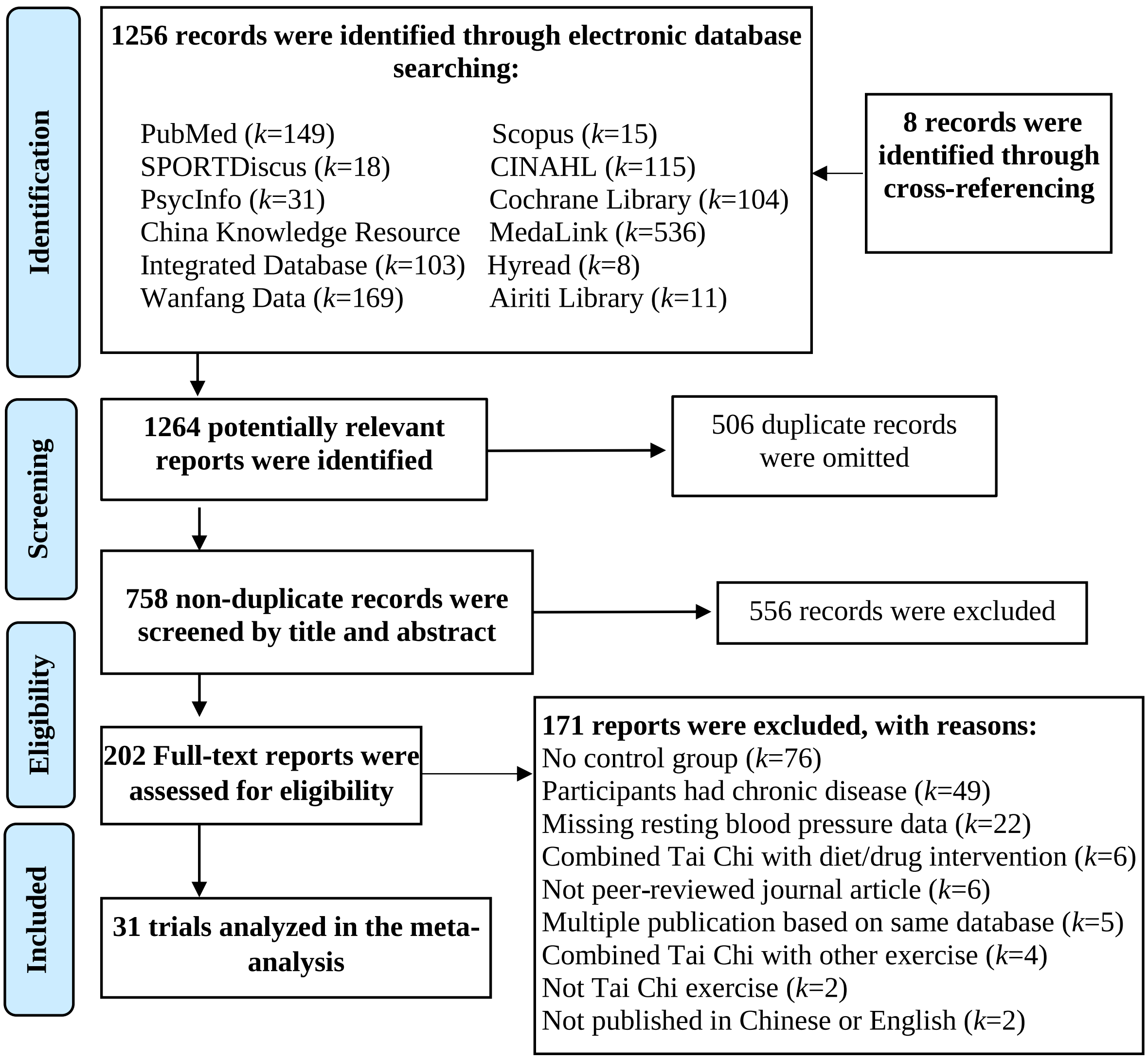


Figure 1. Flow chart detailing the systematic search of potential reports and selection process of included Tai Chi trials

Table 1. Tai Chi Intervention Characteristics

Ex R_x and Instructional Methods	*k*	*M*ean±SD (range)	Reporting Rate[a]
Ex R_x Items			
Frequency (sessions/week)	31	4.0±1.4 (2.0, 7.0)	100.0%
Intensity[b]	12	—	38.7%
	1	Disclosed	
	11	Monitored, not disclosed	
Time (minutes/session)	29	54.0±10.6 (30.0, 65.0)	93.5%
Length of Intervention (week)	22	22.3±20.2 (6.0, 104.0)	100.0%
Instructional Methods Items			
Style[b]	16	—	51.6%
	15	Yang style	
	1	Chen style	
Number of Forms	24	30.4 ± 25.4 (6.0, 108.0)	77.4%
Form names	8	—	25.8%
Movement Principles Emphasized	4	—	19.4%
Breathing Techniques Emphasized	6	—	22.7%
Relaxation Emphasized	3	—	9.7%
Progression[b]	10	—	32.3%
	8	Designated leaning phase	
	2	Gradually increased duration	
Number of Instructors[b]	14	1.4±0.9 (1.0, 4.0)	45.2%
	10	Single instructor	
	4	Multiple instructors	
Credentials of Instructors[b]	18	—	58.1%
	5	Experienced	
	2	Master or expert	
	4	Professional	
	5	Trained or qualified	
	2	Physical education teacher, or health care professional	
Unsupervised Practice[b]	5	—	16.1%
	5	Encouraged, but did not disclose actual time spent	

Note. Summary statistics are based on 31 Tai Chi trials (*k*) and are presented as *M*ean ± SD, unless otherwise stated; Range represents the *M*inimum, *M*aximum values reported for the particular item. — indicates that an item is not applicable. ***Abbr.*** Ex R_x=exercise prescription; SD=standard deviation. **[a]** Reporting rate is expressed as a percentage of trials that reported the specific item out of the total number of trials=31. **[b]** For these Tai Chi intervention characteristics, the subcategories are listed with the frequency they appeared among those trials that reported the item.

Table 2. Moderator and Additive Models: SBP Response to Tai Chi (*k*=31)

Moderator Dimension/Level	$\hat{d}_+$ (95% *CI*) †	B	*P*	SBP Δ (mmHg)
Publishing Language				
Published in Chinese (*k*=13)	-1.11 (-1.39, -0.83)	-.391	.005	-16.7 (-20.9, -12.5)
Published in English (*k*=18)	-0.56 (-0.79, -0.32)			-8.4 (-11.9, -4.8)
Baseline SBP of Sample, mmHg		-.258	.045	
Normal=113±5 (*k*=5)	-0.55 (-0.88, -0.22)			-8.3 (-13.2, -3.3)
Prehypertension=130±6 (*k*=10)	-0.75 (-0.94, -0.55)			-11.3 (-14.1, -8.3)
Hypertension=148±9 (*k*=16)	-0.96 (-1.18, -0.75)			-14.4 (-17.7, -11.3)
Publication Bias (*SE* of the SBP response to Tai Chi**)**		-.329	.017	
Additive Regression Model: 1) among samples with hypertension; and 2) controlling for publication bias				
Published in Chinese	-1.24 (-1.54, -0.94)			-18.6 (-23.1, -14.1)
Published in English	-0.69 (-0.96, -0.41)			-10.4 (-14.4, -6.2)

Note. Baseline SBP is presented as Mean±standard deviation. β=Standardized coefficient represents unique variance explained by moderator. Δ=change. SBP=systolic blood pressure. *SE*= standard error. *CI*=confidence interval. *k*=number of observations.
*Multiple R^2 (variance explained by model, adjusted for number of moderators) =45.3%.

Table 3. Moderator and Additive Models: DBP Response to Tai Chi (*k*=31)

Moderator Dimension/Level	$\hat{d}_{+}$ (95% *CI*) †	B	*p*	DBP Δ (mmHg)
Publishing Language				
Published in Chinese (*k*=13)	-0.85 (-1.04, -0.67)	-.495	<.001	-7.7 (-9.4, -6.0)
Published in English (*k*=18)	-0.32 (-0.46, -0.18)			-2.9 (-4.1, -1.6)
Baseline DBP of Sample, mmHg		-.464	<.001	
Normal=73±4 (*k*=5)	-0.31 (-0.49, -0.13)			-2.8 (-4.4, -1.2)
Prehypertension=81±4 (*k*=10)	-0.53 (-0.64, -0.41)			-4.8 (-5.8, -3.7)
Hypertension=88±8 (*k*=16)	-0.71 (-0.83, -0.59)			-6.4 (-7.5, -5.3)
Additive Model: 1) among samples with hypertension				
Published in Chinese	-0.98 (-1.15, -0.80)			-8.8 (-10.4, -7.2)
Published in English	-0.44 (-0.61, -0.28)			-4.0 (-5.5, -2.5)

Note. Baseline DBP is presented as Mean±standard deviation. β=Standardized coefficient represents unique variance explained by moderator. Δ=change. DBP=diastolic blood pressure. *CI*=confidence interval. *k*=number of observations. *Multiple R^2 (variance explained by model, adjusted for number of moderators) =65.9%.

Table 4. Comparisons of the Sample, Tai Chi Intervention and Study Characteristics between Tai Chi Trials Published in Chinese and English

	Published in Chinese (k=13)		Published in English (k=18)	
	k^a	*M*ean±SD	k	*M*ean±SD
Sample Characteristics				
Age (years)	8	51.9±14.9	15	59.2±16.3
Female (%)	10	78.3±23.9	16	64.0±18.7
BMI (Kg/m^2)	6	24.4±1.6	12	24.6±1.7
Baseline SBP (mmHg)	13	139.1±16.0	18	135.3±14.8
Baseline DBP (mmHg)	13	87.4±10.3	18	80.5±6.0*
No Tai Chi Practice in the Past 6 Months	1	7.7%	6	33.3%
Tai Chi Intervention Characteristics				
Time (minutes/session)	12	47.9±13.7	17	58.4±4.5*
Weekly Time (minute)	12	210.0±77.4	18	215.3±90.1
Total Time of Intervention (minute)	12	4016.7±2760.1	18	4481.5±3135.3
Frequency (sessions/week)	13	4.6±1.2	17	3.6±1.5
Intervention Length (weeks)	13	21.8±25.2	18	22.6±16.6
Reported Intensity of Tai Chi Practice	0	0%	1	5.5%
Did Emphasize Movement Principles	1	3.2%	3	9.7%
Did Emphasize Breathing	4	30.8%	2	11.1%
Did Emphasize Relaxation	1	7.7%	2	11.1%
Study Characteristics				
Sample Size	13	73.8±35.1	18	125.8±87.1
Publication Year	13	2011.1±3.8	18	2011.4±5.7
Methodological Study Quality (%)	13	37.0±10.8	18	60.0±12.6*
Adopted RCT Design	3	23.1%	11	61.1%*
BP was Primary Outcome	12	92.3%	12	66.7%
SE of the SBP Response to Tai Chi	13	0.28±0.08	18	0.22±0.08*
SE of the DBP Response to Tai Chi	13	0.27±0.08	18	0.22±0.08

Note. [a]k=number of Tai Chi trials that reported each item; *P<.05 based on ANOVA test for continuous variables and Pearson's Chi Square test for categorical variables. BMI=body mass index; RCT=randomized controlled trials; SE=standard error; SBP=systolic blood pressure; DBP=diastolic blood pressure; SD=standard deviation.

SUPPLEMENTAL MATERIAL

Data S1: Full search strategy for each of the five electronic databases queried: PubMed, Scopus (including EMBASE), SPORTDiscus, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and PsycInfo. For each search listed below, no start date was applied, and databases were searched from their inception or date of the earliest available publication.

PubMed (including MEDLINE)	Coverage: Date of inception 1940's – July 31st, 2018
Vendor/platform: National Library of Medicine	Hits: 149

PubMed was searched with appropriate Medical Subject Headings (MeSH) incorporated into hedges. Filters were set for Humans:

("mean arterial" OR "blood pressure"[mesh] OR "blood pressure" OR "blood pressures" OR "arterial pressure" OR "arterial pressures" OR hypertension OR hypotension OR normotension OR hypertensive OR hypotensive OR normotensive OR "systolic pressure" OR "diastolic pressure" OR "pulse pressure" OR "venous pressure" OR "pressure monitor" OR hypotension OR "pre hypertension" OR "bp response" OR "bp decrease" OR "bp reduction" OR "bp monitor" OR "bp monitors" OR "bp measurement") AND ("Tai Chi" OR Taichi OR "T'ai Chi" OR "Tai Ji" OR "Tai-Ji" OR Taijiquan)

Scopus (including EMBASE)	Coverage: Date of inception 1960 – June 31st, 2018
Vendor/platform: Elsevier SciVerse	Hits: 15

Search #1:
Line 1: [mean arterial] OR [blood pressure] OR [blood pressures] OR [arterial pressure] OR [arterial pressures] OR hypertension OR hypotension OR normotension OR hypertensive OR hypotensive OR normotensive OR [systolic pressure] OR [diastolic pressure]
OR Line2: [pulse pressure] OR [venous pressure] OR [pressure monitor] OR hypotension OR [pre hypertension] OR [bp response] OR [bp decrease] OR [bp reduction] OR [bp monitor] OR [bp monitors] OR [bp measurement]
Search #2:
Line 1: "Tai Chi" OR Taichi OR "T'ai Chi" OR "Tai Ji" OR "Tai-Ji" OR Taijiquan
Then under search history: combined search #1 and #2

SPORTDiscus	Coverage: Date of inception 1975 – June 31st, 2018
Vendor/platform: EbscoHost	Hits: 18

Line 1: "mean arterial" OR "blood pressure" OR "blood pressures" OR "arterial pressure" OR "arterial pressures" OR hypertension OR hypotension OR normotension OR hypertensive OR hypotensive OR normotensive OR "systolic pressure" OR "diastolic pressure" OR "pulse pressure" OR "venous pressure" OR "pressure monitor" OR hypotension OR "pre hypertension" OR "bp response" OR "bp decrease" OR "bp reduction" OR "bp monitor" OR "bp monitors" OR "bp measurement"

AND line 2: "Tai Chi" OR Taichi OR "T'ai Chi" OR "Tai Ji" OR "Tai-Ji" OR Taijiquan	
CINAHL Vendor/Platform: EbscoHost	Coverage: Date of inception 1981 – June 31st, 2018 Hits: 115
CINAHL hits excluded MEDLINE records. **Line 1**: "mean arterial" OR "blood pressure" OR "blood pressures" OR "arterial pressure" OR "arterial pressures" OR hypertension OR hypotension OR normotension OR hypertensive OR hypotensive OR normotensive OR "systolic pressure" OR "diastolic pressure" OR "pulse pressure" OR "venous pressure" OR "pressure monitor" OR hypotension OR "pre hypertension" OR "bp response" OR "bp decrease" OR "bp reduction" OR "bp monitor" OR "bp monitors" OR "bp measurement" **AND Line 2**: "Tai Chi" OR Taichi OR "T'ai Chi" OR "Tai Ji" OR "Tai-Ji" OR Taijiquan	
PsycInfo Vendor/Platform: EbscoHost	Coverage: Date of inception 1967 – June 31st, 2018 Hits: 31
Line 1:"mean arterial" OR "blood pressure" OR "blood pressures" OR "arterial pressure" OR "arterial pressures" OR hypertension OR hypotension OR normotension OR hypertensive OR hypotensive OR normotensive OR "systolic pressure" OR "diastolic pressure" OR "pulse pressure" OR "venous pressure" OR "pressure monitor" OR hypotension OR "pre hypertension" OR "bp response" OR "bp decrease" OR "bp reduction" OR "bp monitor" OR "bp monitors" OR "bp measurement" **AND Line 2**: "Tai Chi" OR Taichi OR "T'ai Chi" OR "Tai Ji" OR "Tai-Ji" OR Taijiquan	
Cochrane Library Vendor/Platform: Wiley Online Library	Coverage: Date of inception 1999 – June 31st, 2018 Hits: 104
Line 1:"mean arterial" OR "blood pressure" OR "blood pressures" OR "arterial pressure" OR "arterial pressures" OR hypertension OR hypotension OR normotension OR hypertensive OR hypotensive OR normotensive OR "systolic pressure" OR "diastolic pressure" OR "pulse pressure" OR "venous pressure" OR "pressure monitor" OR hypotension OR "pre hypertension" OR "bp response" OR "bp decrease" OR "bp reduction" OR "bp monitor" OR "bp monitors" OR "bp measurement" **AND Line 2**: "Tai Chi" OR Taichi OR "T'ai Chi" OR "Tai Ji" OR "Tai-Ji" OR Taijiquan	
Chinese Knowledge Resource Integrated Database	Coverage: Date of inception 1999 – June 31st, 2018 Hits: 103
“高血压”并且 (“太极”或者 “太极拳”)	
Wanfang Data	Coverage: Date of inception 1950 – June 31st, 2018 Hits: 169

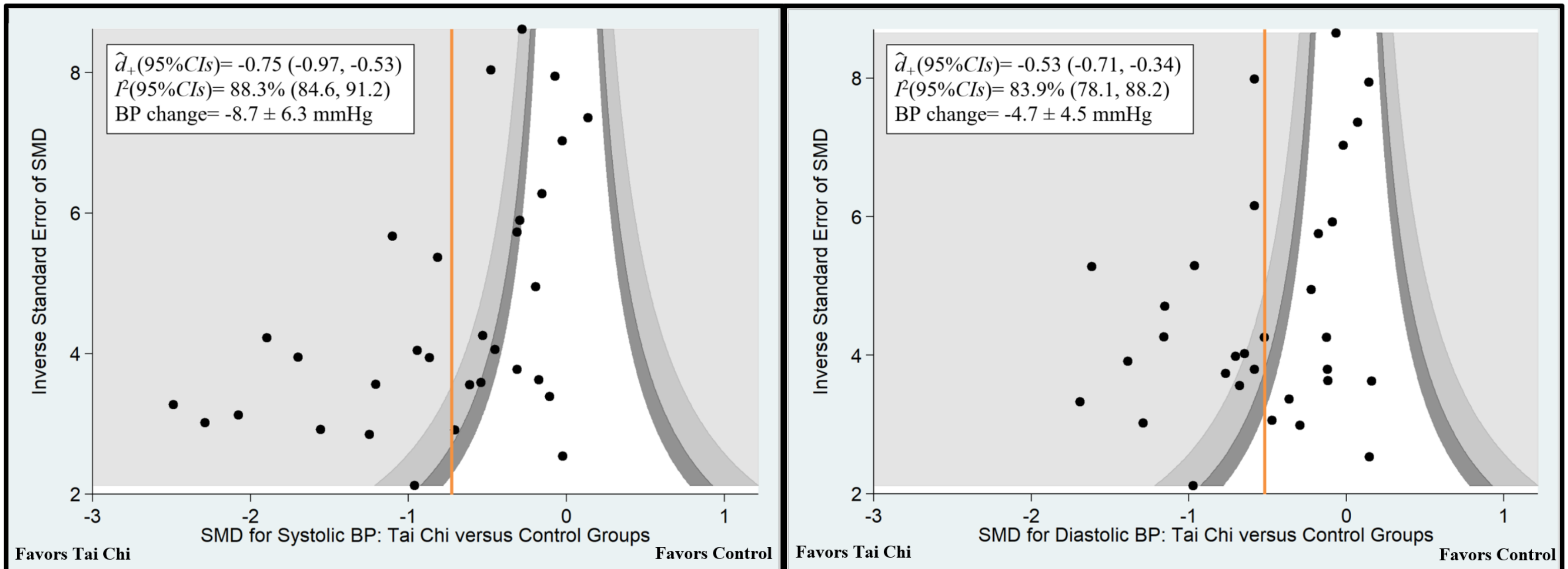
“高血压”并且 (“太极”或者 “太极拳”)	
Medalink	Coverage: Date of inception 1999 – June 31st, 2018 Hits: 536
Medalink included Chinese Knowledge Resource Integrated Database and Wanfang Data records “高血压”并且 (“太极”或者 “太极拳”)	
Hyread	Coverage: Date of inception 1954 – June 31st, 2018 Hits: 8
“高血壓”並且 (“太極”或者 “太極拳”)	
Airiti Library	Coverage: Date of inception 1999 – June 31st, 2018 Hits: 11
“高血壓”並且 (“太極”或者 “太極拳”)	

Data S2. Stata Commands used in Meta-Analysis	
Function/Analysis	**Stata Commands**
Create new variable	gen
Generate descriptive data	sum, total, tab
Examine correlations	pwcorr
Calculate mean effect sizes	meanes
Create funnel plots	confunnel
Begg and Egger tests	metabias
PET-PEESE	metareg
Bivariate analysis	metaf for categorical variables metareg for continuous variables
Multiple-moderator analysis and moving constant technique	metareg

Data S3. Baseline Sample Characteristics of the Tai Chi and Control Intervention Groups (*k*=31)

	k	**Tai Chi (*n*=1,654)**	**Control (*n*=1,569)**
Age (year)	23	57.6±16.5	54.9±15.9
Female (%)	26	72.5±22.2	67.2±20.9
BMI (kg/m^2)	18	24.7±1.4	24.3±1.9
Baseline SBP (mmHg)	31	138.2±17.0	135.4±13.1
Baseline DBP (mmHg)	31	83.4±9.4	83.4±8.4

Note. Statistics are summarized as Mean±*SD*; *k*=number of observations; *n*=number of participants. BMI=body mass index; SBP=systolic blood pressure; DBP=diastolic blood pressure



Data S4. The standardized mean difference in systolic and diastolic blood pressure after Tai Chi versus control intervention. *Note*. Weighted mean effect sizes value (d_+) are negative when Tai Chi reduced systolic and diastolic BP compare to control. ***Abbr.*** BP= blood pressure. SMD= Standardized mean difference. *CI*= confidence interval. The orange lines indicate the overall mean effect sizes.

Data S5. Variables that were tested, but were not significant moderators of the Blood Pressure responses to Tai Chi

	SBP	DBP
Variables related to study design	Randomized controlled trials vs. not Blood pressure as the primary outcome vs. not* Sample size* Trial location: China vs. non-Chinese Asian countries vs. non-Asian countries* Publication year Methodological study quality*	Randomized controlled trials vs. not Blood pressure as the primary outcome vs. not* Sample size Trial location: China vs. non-Chinese Asian countries vs. non-Asian countries* Publication year Methodological study quality* SE of the DBP response to Tai Chi
Variables related to sample characteristics	Age Percent of female participants Body Mass Index	Age Percent of female participants Body Mass Index
Variables related to Tai Chi practice	Number of days of Tai Chi practice per week Minutes of Tai Chi practice per session* Minutes of Tai Chi practice per week Minutes of Tai Chi practice per intervention Length of Tai Chi interventions in weeks Emphasized movement principles vs. not Emphasized relaxation vs. not Emphasized breathing techniques vs. not* Reported Tai Chi related credentials for instructors vs. not	Number of days of Tai Chi practice per week* Minutes of Tai Chi practice per session* Minutes of Tai Chi practice per week Minutes of Tai Chi practice per intervention Length of Tai Chi interventions in weeks Emphasized movement principles vs. not Emphasized relaxation vs. not Emphasized breathing techniques vs. not* Reported Tai Chi related credentials for instructors vs. not*

Note. * indicates that variable was significant in bi-variate analysis; however, not significant in the final multiple-moderator model for SBP or DBP

Chapter 4. A Comparison of Two Tai Chi Interventions Tailored for Different Health Outcomes

Yin Wu[1], Cindy Senk[2], Patrick Coll[2,3], Susan Glenney[1], Ken Zaborowski[1], Richard Fortinsky[3], Beth Taylor[1], Crystal L. Park[4], Kirsten Benson[2], Matt McGowan[2], Slyvia DiBiasi[2], Ming-Hui Chen[5], and Linda S. Pescatello[1]

[1] Department of Kinesiology, University of Connecticut, Storrs, CT, USA

[2] Seabury Life Care Community, Bloomfield, CT, USA

[3] Center on Aging, University of Connecticut Health Center, Farmington, CT, USA

[4] Department of Psychological Science, University of Connecticut, Storrs, CT, USA

[5] Department of Statistics, University of Connecticut, Storrs, CT, USA

Research Support: Seabury Charitable Foundation at Seabury Life Care Community

Institute for Collaboration on Health, Intervention, and Policy at University of Connecticut

Connecticut Institute for Clinical and Translational Science

Center on Aging at University of Connecticut Health Center

Correspondence: Yin Wu, M.A.

Department of Kinesiology, 2095 Hillside Road Unit 1110

University of Connecticut, Storrs, CT 06269-1110, USA.

Telephone: (860) 929-6382 Fax: (860) 486-1123 Email: yin.2.wu@uconn.edu

Abstract

Tai Chi has demonstrated salutary health benefits, but whether tai chi interventions tailored for specific health outcomes will result in different health benefits remains unknown. Therefore, we compared the health benefits of two different Tai Chi interventions targeted for improvements in either blood pressure (BP) (PRESSURE) or balance (BALANCE). We tailored PRESSURE to emphasize breathing techniques and mental relaxation and BALANCE to emphasize movement principles that challenged balance. Subjects were randomized to PRESSURE (n=12), BALANCE (n=13), or CONTROL (n=10). Tai Chi was practiced 3 sessions/wk, 60 min/session for 12 wk. CONTROL performed daily activities. We tested the change in cardiometabolic health, balance, and functional fitness outcomes among groups with analyses of covariance with the health outcome baseline value, age, and body mass index as covariates adjusted for multiple comparisons. Subjects were physically active, Tai Chi naive (97.1%), white and older (78.9±5.7yr) with systolic BP (SBP) of 126.5±14.4 mmHg and diastolic BP of 69.3±8.4mmHg, and mostly female (82.9%). PRESSURE improved Chair Sit-to-Stand Test (CSTS) (1.0±1.8 vs. -0.6±0.8times/30sec, P=.03) versus CONTROL, and gait speed (12.8±43.3 vs. -24.1±22.4cm/sec, P=.02) versus BALANCE. Meanwhile, BALANCE improved Single Leg Stance Test (5.4±18.0 vs. -8.2±10.3sec, p=.049) and CSTS (1.0±1.7 vs. -0.6±0.8times/30sec, p=.03), and tended to lower SBP (-4.2±16.0 vs. 3.5±8.3mmHg, p=.052) versus CONTROL. Within just 3 months, physically active, Tai Chi naive older adults improved on a variety of health outcomes, independent of the type of Tai Chi practice. Future studies should confirm our findings and determine the sustainability of the accrued health benefits with a longer period of Tai Chi practice among a larger, more ethnically and gender diverse sample.

Keywords: balance, blood pressure, complimentary medicine, older adults

Introduction

By 2030, older adults (≥65 years) will comprise approximately 20% (~72 million) of the population in the United States (US).[1,2] Of note, more than 66% of older adults have two or more chronic diseases or health conditions.[3] Thus, the cost of providing health care for an older adult is three to five times higher than the cost for someone younger than 65 years in the US.[4] Exercise is a low cost, effective lifestyle therapeutic option that provides many health benefits with minimal adverse side effects.[5,6] Various professional committees and organizations recommend older adults perform at least 150 minutes of moderate intensity aerobic exercise, and dynamic resistance exercise on two or more days per week.[7-11] However, about 90% of older adults do not meet these exercise recommendations in the US.[12] Therefore, it is imperative to explore alternative forms of exercise for older adults.

Tai Chi is a low impact,[13] social,[14,15] and enjoyable[16] form of exercise that is particularly suitable for older adults.[17-21] Blood pressure (BP) and balance are the two most studied resultant health outcomes of Tai Chi.[13,22] It is important to note that Tai Chi varies considerably in terms of the styles (e.g., Yang style), forms (e.g., cloud hands), and combinations of breathing techniques, mental relaxation, and movement principles (e.g., emphasizing weight shifting between heel and toe).[23-25] However, after systematically reviewing and meta-analyzing the literature, we found that Tai Chi trials aimed at reducing BP rarely disclosed features relevant to BP as the targeted health outcome, such as the emphasis on breathing techniques (19.4%) and mental relaxation (9.7%) or the intensity (35.5%) of Tai Chi practice.[26] Meanwhile, Tai Chi trials aimed at improving balance rarely disclosed important features relevant to balance improvement such as the emphasis on movement principles (51.9%), or the names of Tai Chi forms selected (14.8%).[27] Our review of the literature indicates that Tai Chi is rarely tailored for the health outcomes being targeted in these research studies.[26,27]

Therefore, whether Tai Chi tailored for different health outcomes will result in different health benefits remains unknown. Lack of such knowledge may hinder the ability of health care and exercise professionals to effectively recommend and promote Tai Chi exercise to their older patients and clients to maximize the health benefits that can be accrued.[28] Therefore, we conducted a pilot study to compare the resultant health benefits of two different Tai Chi interventions, one specifically tailored for reductions in BP (PRESSURE) and the other for improvements in balance (BALANCE) among community dwelling older adults. We hypothesized that PRESSURE would elicit statistically significantly greater BP reductions compared to BALANCE; meanwhile, BALANCE would elicit statistically significantly greater improvements in balance measures than PRESSURE.

Methods

Overview

We employed a randomized controlled design (Figure 1). Our study was conducted from November 2017 to November 2018 at the Seabury Life Care Community (referred as Seabury from here on in), Bloomfield, CT. After signing the informed consent, subjects who were eligible for the study: 1) attended Visits 1 and 2 for pre-intervention measurements; 2) were randomized to PRESSURE, BALANCE, or the control group (CONTROL); 3) practiced Tai Chi if assigned to PRESSURE or BALANCE, and performed regular daily activities if assigned to CONTROL; and 4) attended Visit 3 for post-intervention measurements. All study procedures were approved by the Institutional Review Board at the University of Connecticut.

[INSERT FIGURE 1 HERE]

Subjects and Randomization

The study was advertised through flyers and the in-house TV channel at Seabury. Seabury enrollees were eligible if they: 1) were ≥60 years of age; 2) had resting systolic BP (SBP) <160 and diastolic BP (DBP) <100 mmHg; and 3) were medically cleared to participate in the Tai Chi sessions by their primary care physicians. All subjects provided informed consent to be enrolled in the study. After the completion of Visit 1 and 2, subjects were randomly assigned via www.randomzation.com to PRESSURE (*n*=16), BALANCE (*n*=16), or CONTROL (*n*=10).

The Tai Chi Interventions

Subjects in both PRESSURE and BALANCE practiced Tai Chi for 3 sessions/week, 60 minutes/session for 12 weeks in the dance studio on the Seabury campus, and were instructed not to practice Tai Chi outside of the Tai Chi interventions. Each Tai Chi session consisted of 15 minutes of warm-up exercise, 40 minutes of Tai Chi practice, and 5 minutes of cool-down exercise. All Tai Chi sessions were led by a professional, certified Tai Chi instructor (KZ) who had more than 20 years of experience teaching Tai Chi, and was teaching Tai Chi at several senior centers in CT. To help the subjects gradually learn the Tai Chi practice, new Tai Chi forms were added into the existing routine one at a time. In addition, we provided chairs for resting during Tai Chi sessions and modified Tai Chi forms to subjects' physical limitations when needed to ensure the safety of the subjects.

Both the PRESSURE and BALANCE Tai Chi routines consisted of eight Tai Chi forms following Yang style. However, PRESSURE and BALANCE were tailored differently for the targeted health outcomes of BP or balance in consultation with the professional, certified Tai Chi instructor (KZ) and an experienced physical therapist (SG). Specifically, we tailored PRESSURE to emphasize slow, deep breathing and relaxation by utilizing Tai Chi movements that: 1) were slow and smooth; 2) without break or pause; and 3) had minimal muscular force and exertion.[25,29,30] We included the following eight Tai Chi forms in PRESSURE: 1) Begin Tai Chi;

2) Part the Horse's Mane; 3) Brush Knee and Push; 4) Cloud Hands; 5) Open and Close; 6) Part the Grass; 7) Single Whip; and 8) Finish Tai Chi.[31] Meanwhile, we tailored BALANCE to provide moderate to high levels of challenge to balance control by emphasizing movement principles (e.g., consciously control weight shifting between legs and from heel to toe during multi-directional stepping), and integrating Tai Chi movements that: 1) reduced the base of support; 2) moved the center of gravity; and 3) improved lower-extremity strength.[32,33] We included the following eight forms in BALANCE: 1) Begin Tai Chi; 2) Roll the Ball; 3) Kick with Heel; 4) Repulse the Monkey; 5) Gather the Earth's Qi; 6) White Crane Spread Wing; 7) Fairy Weaves the Shuttle; and 8) Finish Tai Chi.[31]

Meanwhile, subjects in CONTROL performed their regular habitual daily activities throughout the 12 weeks. Furthermore, all subjects were instructed to maintain their diet, and regular level of physical activity throughout the study, and inform the researchers of any changes in medication use. Of note, both PRESSURE and BALANCE were made available for subjects in CONTROL after the completion of post-intervention measurements.

Health Outcome Measures

We administered measures of cardiometabolic health, balance, functional fitness, and habitual physical activity in Visit 1 and 2 (i.e., pre-intervention), and within 24-48 hours following the last Tai Chi session (i.e., Visit 3, post-intervention). One exception was that subjects only wore the Actical physical activity accelerometer (Philips Respironics/Philips MiniMitter®, Bend, OR) at pre-intervention. In addition, once per week (12 times in total), we monitored the heart rate of subjects during a Tai Chi session with the Polar® heart rate monitor model FT7 (Polar Electro, Kempele, Finland), and asked subjects to rate the intensity of Tai Chi using the Borg Rating of the Perceived Exertion Scale at the end of each Tai Chi session.[34-36]

Cardiometabolic Health

Resting BP and heart rate were measured with the OMRON® automated BP monitor (model HEM-705CPN OMRON, Kyoto, Japan) in adherence to standards set forth by the American Heart Association.[37-39] Subjects sat for 10 minutes after which BP and heart rate were measured three times, one minute apart in the non-dominant arm and averaged. The trained investigator took BP measurements until three readings were obtained that agreed within 5 mmHg, and these BP values and the corresponding heart rate values were averaged and recorded as resting BP in mmHg and resting heart rate in beats/minute. Body mass index (BMI) was calculated from height and weight [i.e., BMI=Kg/m^2][33] measured with a professional scale (Health o meter®597KL [Pelstar, Bridgeville, IL]). Waist circumference (cm) was measured at the height of the iliac crest with a Gullick tape measure.[33,40]

Balance

For the Single Leg Stance Test, subjects balanced on their dominant leg for as long as possible.[41] A trained investigator measured the time in seconds of successful balance using a handheld stopwatch. Each subject performed three trials with 30 seconds of rest in between with the best score (the longest time) used for data analysis. The Postural Stability Test was administered with the Biodex Balance System SD (Biodex Medical Systems, Shirley, USA) with the platform stability set at 8 (12 is the most stable, 1 is the least stable) following the default settings.[42] Subjects stood on the platform with both feet while remaining as still as possible.[42-44] Each subject performed three 20-second trials, with 10 seconds of rest in between. The medial-lateral stability index, the anterior-posterior stability index, and the overall stability index were calculated for each trial, and then averaged by the Biodex software (Biodex Medical Systems, Inc., version 1.3.4) for data analysis following the default setting.[42] For the Timed Up and Go

Test, subjects stood up from a chair, walked three meters as quickly as they could to a mark on the floor, turned and sat back down on the chair.[45] A trained investigator measured the time in seconds used to finish the trial using a handheld stopwatch. Each subject performed one practice trial, and one test trial with 30 seconds of rest in between. Time used in the test trial was used for data analysis. For the Four Square Step Test, subjects stepped in a predetermined sequence as quickly as they could, over four 90-cm-long walking sticks placed in a cross configuration on the ground.[46] For a complete trial, each subject stepped forward, to the right, backward, and to the left into each quadrant in the clockwise direction, followed by the reverse sequence in the counterclockwise direction.[46] A trained investigator measured the time in seconds used to finish the trial using a handheld stopwatch. After one practice trial, each subject performed three test trials with the best score (shortest time) used for data analysis.

Functional Fitness

For the Hand Grip Test, subjects held a calibrated Jamar Hydraulic Handgrip Dynamometer model 5030J1 (Lafayette Instrument Co., Lafayette, IN) and squeezed as hard as they could with their dominant hand.[47,48] Each subject performed two trials with one minute of rest in between, sitting with the arm against the trunk and the elbow flexed 90 degrees on the tested side.[49] The mean of the two readings in Kg was used for data analysis. For the Chair Sit-to-Stand Test, subjects stood up from a chair until the legs were straight and sat down with their full weight placed on the chair as quickly as possible.[50] A trained investigator counted the number of repetitions completed in 30 seconds. Each subject completed two trials with five minutes of rest in between. The average number of chair stand repetitions from both trials was used for data analyses. For the Chair Sit-and-Reach Test, subjects sat in a chair with one leg extended and the other bent, then reached down and forward slowly in an attempt to touch the toes of the extended leg.[51,52] Subjects held a brief static position for 2 seconds, while a trained investigator recorded the distance between the tips of the middle fingers and the middle of the toe at the end of the shoe in cm using an 18-inch (46 cm) ruler positioned parallel to the shin. After a short warm-up, each subject performed two trials with 10 seconds of rest in between with the better score on each leg used for data analysis. For the 10-Meter Walk Test, subjects walked as fast as possible through a 15-meter walking path with 2.5 meters provided for acceleration and deceleration on each end.[53] A trained investigator measured the seconds used to pass the data collection area at 10 meters with a handheld stopwatch. Each subject performed two trials with one minute of rest in between. The fast walking speed (cm/second) was calculated based on the shortest time and used for data analysis.

Physical Activity Participation

We used the Actical physical activity accelerometer (Philips Respironics/Philips MiniMitter, Bend, OR) at pre-intervention to measure the habitual physical activity levels of subjects.[54] Subjects wore the accelerometer at the waist line for four consecutive days (two weekdays and two weekend days), and only removed it when swimming, bathing, showering, or sleeping. The average time spent (minutes/day) in sedentary behavior and light, moderate, and vigorous intensity physical activity, and steps per day were recorded and used for data analysis. In addition, we administered the Paffenbarger Physical Activity Questionnaire at pre-and post-intervention to assess subjects' habitual physical activity level that included leisure-time activities and formal exercise.[55,56] The energy expenditure (Kcal/day) in light, moderate, and vigorous intensity physical activity, and the energy expenditure (Kcal/week) in leisure-time physical activity and formal exercise were calculated and used for data analysis. Of note, for both measures, sedentary behavior was defined as <1.5 metabolic energy equivalents (METs), light intensity physical activity was defined as 1.5 to <3.0 METs, moderate intensity physical activity was defined as 3.0 to <6.0 METs, and vigorous intensity physical activity was defined as >6.0 METs.[57]

Statistical Analyses

Data analysis was performed on the subjects (*N*=35) who completed the study. Descriptive values are presented in mean±standard deviation unless stated otherwise. For each subject, we also calculated: 1) adherence rate (i.e., [number of attended Tai Chi sessions/number of possible sessions=36]X100); 2) intensity of Tai Chi practice indicated by the percent of age predicted maximal heart rate (i.e., the mean of the heart rate values during each of the 12 Tai Chi session/[208-0.7Xage]X100);[58] and 3) intensity of Tai Chi practice indicated by the Borg Rating of the Perceived Exertion Scale scores (i.e., the mean of the Borg Rating of the Perceived Exertion Scale scores of each of the 12 Tai Chi session). Normality of cardiometabolic health, balance, and functional fitness outcomes was checked and no evidence against the assumption was found. Between-group differences in baseline characteristics were tested with Pearson's Chi-Square for the categorical variables, and analysis of variance (ANOVA) for the continuous variables. Within-group differences post- versus pre-intervention were tested with a paired T-Test. Between-group differences in the change of the cardiovascular health, balance, and functional fitness outcomes post- versus pre-intervention were tested with analyses of covariance (ANCOVA) with the health outcome baseline value, age, BMI, and heart rate as covariates. Post-hoc analyses following the Bonferroni procedure for multiple comparisons was performed when there was significant ($P<.05$) or trending ($P<.1$) between-group difference. Significance was established at an alpha level of $P<.05$. All statistical analyses utilized SPSS 25.0 (Armonk, NY: IBM Corp).

RESULTS

Figure 1 presents the adapted CONSORT flow diagram showing the five phases of study from enrollment to data analysis. In total, 63 Seabury enrollees expressed interest in the study and attended an orientation session, and 42 signed an informed consent form. All 42 subjects were considered eligible for the study and were randomized into PRESSURE (*n*=16), BALANCE (*n*=16), or CONTROL (*n*=10). At post-intervention measurements (i.e., visit 3), seven subjects (16.7%) dropped out from the study (i.e., four from PRESSURE, three from BALANCE). Reasons for dropping out included schedule conflicts (*n*=2) and change of health status (*n*=5). There were no adverse events related to Tai Chi practice during our study.

The Tai Chi Interventions

Among the 35 subjects who completed the study, subjects in PRESSURE attended 2.8±0.2 Tai Chi sessions per week on average, and subjects in BALANCE attended 2.9±0.2 Tai Chi sessions per week on average (*P*>.05). In addition, the adherence rate of the possible 36 Tai Chi sessions was 92.1±6.4% for PRESSURE and 95.1±6.7% for BALANCE (*P*>.05). The average intensity of Tai Chi practice also did not differ between PRESSURE and BALANCE (*P*s>.05), indicated by: 1) the percent of the age predicted maximal heart rate achieved during the 12 Tai Chi sessions of 57.5±7.8% for PRESSURE and 51.8±6.3% for BALANCE; and 2) the self-reported Borg Rating of the Perceived Exertion Scale of 10.1±0.9 for PRESSURE and 10.2±3.7 for BALANCE during the 12 Tai Chi sessions.

Subject Baseline Characteristics

Baseline characteristic are presented in Table 1. Overall, subjects were white (*n*=35, 100.0%) older adults (78.9±5.7 years) with SBP of 126.5±14.4 mmHg and DBP of 69.3±8.4 mmHg, mostly female (*n*=29, 82.9%) and naive to Tai Chi practice (*n*=34, 97.1%). Most of the subjects (*n*=31, 88.6%) reported taking, on average, 3.0±2.3 different prescription medications. The top three categories of reported prescription medications were antihypertensive medication (*n*=16, 45.7%), statins (*n*=10, 32.2%), and thyroid medication (*n*=9, 25.7%). Among the subjects who reported taking antihypertensive medications, the top three reported types were beta-blockers (*n*=9, 25.7%), diuretics (*n*=7, 20.0%), and angiotensin-converting-enzyme inhibitors (*n*=5, 14.3%). Of note, subjects participated in 56.0±32.4 minutes/day of moderate intensity physical activity and took 3992.8±2287.4 steps/day assessed by accelerometry, which categorized them in the top 10 percent of physically active older adults in the US.[59,60] Baseline characteristics were similar between groups except subjects in PRESSURE had: 1) higher DBP than BALANCE (*P*=.047); and 2) higher heart rate than BALANCE (*P*=.03) and CONTROL (*P*=.001).

Resultant Health Benefits

Tables 1 and 2 present the change in the measures of cardiometabolic health, balance, functional fitness, and physical activity level outcomes post- versus pre-intervention.

Cardiometabolic Health Measures

There were no statistically significant within-group differences in the change of any of the cardiometabolic health measures, including BP, among PRESSURE, BALANCE, or CONTROL (*P*s>.05) post- versus pre-intervention. Meanwhile, there were no statistically significant between-group differences in the change of the cardiometabolic health measures, including BP, post- versus pre-intervention among PRESSURE, BALANCE, and CONTROL (*Ps*>.05). However, there was a trending between-group difference in the change in BP (*P*=.053) such that BALANCE tended to lower SBP more than CONTROL (*P*=.052).

Balance Measures

The time in the Single Leg Stance Test decreased post- versus pre-intervention (26.1±18.4 vs. 34.3±24.4 seconds, P=.03) within CONTROL. There were no other statistically significant within-group differences in the balance measures among PRESSURE, BALANCE, or CONTROL post- versus pre-intervention (Ps>.05). Meanwhile, there was a between-group difference in the change in Single Leg Stance Test (P=.03) such that BALANCE increased the time in Single Leg Stance Test compared to CONTROL (P=.049). There were no other statistically significant between-group differences in the change of any of the other balance measures post- versus pre-intervention among PRESSURE, BALANCE, and CONTROL (Ps>.05).

Functional Fitness Measures

Handgrip strength increased at post- versus pre-intervention (11.1±7.7 vs. 8.9±8.2 Kg, P=.02) within PRESSURE. In addition, the fast walking speed in the 10-Meter Walk Test decreased post- versus pre-intervention (161.9±28.5 vs. 186.0±31.8 cm/second, P=.002) within BALANCE. There were no other statistically significant within-group differences in any of the other functional fitness measures among PRESSURE, BALANCE, or CONTROL post-versus pre-intervention (Ps>.05). Meanwhile, there was a significant between-group difference in the change in the number of repetitions in the Chair Sit-to-Stand Test (P=.04) such that PRESSURE increased the number of repetitions in Chair Sit-to-Stand Test (P=.03) versus CONTROL, and BALANCE increased the number of repetitions in the Chair Sit-to-Stand Test versus CONTROL (P=.03). In addition, there was a between-group difference in the change in fast walking speed in the 10-Meter Walking Test (P=.02) such that PRESSURE increased the fast walking speed in the 10-Meter Walking Test versus BALANCE (P=.02). There were no other statistically significant between-group differences in the change of any of the other functional fitness measures among PRESSURE, BALANCE, and CONTROL (*P*s>.05).

Habitual Physical Activity Level

There were no statistically significant within or between group differences in the change in any measure of habitual physical activity level measured by the Paffenbarger Physical Activity Questionnaire post- versus pre-intervention among PRESSURE, BALANCE, or CONTROL (*P*s>.05).

Discussion

We conducted a rigorously designed randomized controlled pilot study to compare the health benefits of two different Tai Chi interventions, one tailored for lowering BP and the other for improving balance. Our major findings were that Tai Chi naive older adults improved in a variety of health outcomes within just three months; however, contrary to our hypotheses, the accrued health benefits were independent of the type of Tai Chi practice. Specifically, PRESSURE improved Chair Sit-to-Stand Test performance (1.0 vs. -0.6 times/30second) versus CONTROL; meanwhile, BALANCE improved Single Leg Stance Test performance (5.4 vs. -8.2 second), Chair Sit-to-Stand Test performance (1.0 vs. -0.6 times/30second), and tended to lower SBP (-4.2 vs. 3.5 mmHg) versus CONTROL. Collectively, our findings indicate that Tai Chi, regardless of the type of practice, can be recommend to older adults to improve their overall health that includes balance, functional fitness, and SBP.

Currently, about 90% of older adults ≥65 years, and over 95% of older adults ≥85 years are physically inactivity in the US.[7,61,62] Tai Chi has the potential to increase exercise participation among older adults, because it is a safe, low impact, enjoyable, and inexpensive form of exercise.[24,15,63] In addition, Tai Chi practice requires minimum equipment and space, and the length of Tai Chi practice can be easily adjusted to fit into the practitioner's schedule.[25,30] Surprisingly, Tai Chi is still underutilized in the US,[64] with only 2.9% of adults reporting practicing Tai Chi in their life time.[64] Therefore, scientific evidence that can promote the use of Tai Chi and reduce the barriers to initiate Tai Chi practice among older adults is greatly needed.

Our study is the first to directly compare the health benefits of two different types of Tai Chi practice intended for two different health outcomes among older adults. Our novel findings are that with just three months, Tai Chi improved balance, functional fitness, and SBP among highly physically active and Tai Chi naive older adults independent of the type of practice. Improvements in these health outcomes are particularly important for older adults because they represent some of the most potentially serious health issues that an older adult can encounter. For example, approximately 30% of healthy older adults experience a fall annually in the US. Although many falls are associated with multiple risk factors, many are due in part to poor balance.[113] Falls are the leading cause of fatal injury and the most common cause of nonfatal trauma-related hospital admissions among older adults.[65,66] Meanwhile, according to the 2017 American College of Cardiology and American Heart Association Guidelines,[6] 75 to 85% of older adults in the US are now classified as having hypertension.[6] Each 20-mmHg increment in SBP and 10-mmHg increment in DBP increases and eventually doubles the incidence of cardiovascular diseases.[67] Furthermore, we found that the two different Tai Chi interventions were both of low intensity (i.e., ~57% vs. ~52% of age-predicted maximal heart rate), well adhered to (i.e., ~92% and ~95% attendance rate), and without any adverse events, despite the fact that BALANCE included more physically demanding Tai Chi forms that perturbed balance comparing to PRESSURE. Collectively, findings from our study suggest that health care and exercise professionals should consider recommending Tai Chi to their older patients/clients as a safe modality of exercise to improve their overall health. In addition, physically active and relatively healthy older adults may choose any type of Tai Chi practice based on their preference and their access to Tai Chi (e.g., what type of Tai Chi is offered at local senior centers) to initiate Tai Chi practice for its short-term health benefits. However, since our study sample was small, further investigation is needed to confirm our findings and determine the sustainability of the health benefits we observed among a larger, more ethnically and gender diverse sample.

Of note, professional health organizations currently only recommend Tai Chi to older adults for the primary purposes of improving balance and fall prevention among those who are at high risk of falling.[7-11] However, we studied a group of older adults who: 1) were highly physically active; 2) had balance function well above the average for their age (i.e., single leg stance time: ~38 seconds; Timed Up and Go Test time: ~7 seconds);[68,69] and 3) had relatively normal and well controlled BP at baseline, with the average resting SBP of ~127 mmHg and DBP of ~70 mmHg.[70,71] Nonetheless, among this relatively healthy population of older adults, we found that Tai Chi improved performance in the Single Leg Stance Test and the Chair Sit-to-Stand Test that reflect improvements in static balance functions, lower extremity muscle strength, and lower extremity proprioception and tactile sensitivity.[72,73] In addition, Tai Chi lowered SBP ~7 mmHg compared to CONTROL; such magnitude of SBP reductions would lower the elevated baseline SBP levels we found into normal ranges without concomitant medication use.[74] Collectively, findings from our study suggest that Tai Chi may provide even greater benefits to the general population of older adults in the US, who are likely to be less physical active and have less desirable cardiometabolic health, balance, and functional fitness health comparing to the subjects in our study.[75,76] In addition, findings from our study also indicate that professional health organizations should consider recommending Tai Chi to a broader group of older adults than just those who are at high risk of balance. We acknowledge that our study had several limitations. First, our pilot study had a small sample with 12 subjects in PRESSURE, 10 subjects in BALANCE, and 10 subjects in CONTROL which made our multiple-group comparison analyses exploratory and increased our risk of type II errors.[77] However, since our pilot study was the first to compare the resultant health benefits of two different Tai Chi interventions tailored for different health outcomes, no data from previous studies was available for us to perform power analysis and calculate the sample size needed to find detectable differences in BP and balance measures between PRESSURE and BALANCE. Secondly, our sample was not diverse in terms of ethnicity (100% white) or gender (~83% female). Lastly, even though little is known regarding the learning curve of Tai Chi practice or the timing of appearance of the resultant health benefits among older adults,[25,30,78] the length of our intervention (i.e., 12 weeks) may have been insufficient for subjects to master the Tai Chi forms well enough so that they could integrate breathing techniques, mental relaxation, and/or movement principles adequately during Tai Chi practice which may have contributed to the similarities in the findings that resulted from the two different Tai Chi interventions. Due to these limitations, we acknowledge our study is preliminary and our findings should be confirmed by future randomized controlled trials with a longer period of Tai Chi practice among a larger, more ethnically and gender diverse sample.

Despite the noted limitations, our pilot study also possesses several noteworthy strengths. To our best knowledge, our study is the first to compare the health benefits of two different Tai Chi interventions, one tailored for lowering BP, and the other tailored for improving balance. Future Tai Chi intervention studies may consider adopting such research methods to investigate other health outcomes (e.g., cognitive functions) among different populations (e.g., older adults with mild cognitive impairment). All health outcome measures pre- and post-intervention were performed by the same trained investigator to minimize technical errors and inter-rater variability. In addition, all post-intervention measures were performed approximately at the same time of day as the pre-invention measures and between 24 to 48 hours after the last session of Tai Chi to ensure that our results were minimally confounded by circadian variation and acute or detraining effects, respectively,[75,79,80] Of particular importance is that the design and reporting of the two Tai Chi interventions were fully in adherence to and rated 100 percent on an evaluation tool examining the quality of the exercise prescription (e.g., intensity) and instructional methods (e.g., type, name of Tai Chi forms) of Tai Chi interventions.[27] All Tai Chi sessions were led by the same certified and experienced Tai Chi instructor (KZ) to minimize variability in the results introduced by the differences between Tai Chi instructors in relation to Tai Chi expertise, and teaching skills.

In conclusion, findings from our pilot study support the use of Tai Chi to improve balance, functional fitness, and BP among highly physically active, Tai Chi native older adults within just three months. For these reasons, health care and exercise professionals should consider recommending Tai Chi to a broad range of older patients/clients, not just for those who are at high risk of falling. Findings from our pilot study also suggest that for physically active and relatively healthy older adults, the short-term health benefits of Tai Chi are independent of the type of Tai Chi practice; therefore, these older adults may choose the type of Tai Chi based on their personal preference and their access to Tai Chi practice. However, future randomized controlled trials with larger sample size and longer period of Tai Chi practice need to investigate if these findings will be the same among older adults with impairments in balance and functional fitness, or with uncontrolled high BP.

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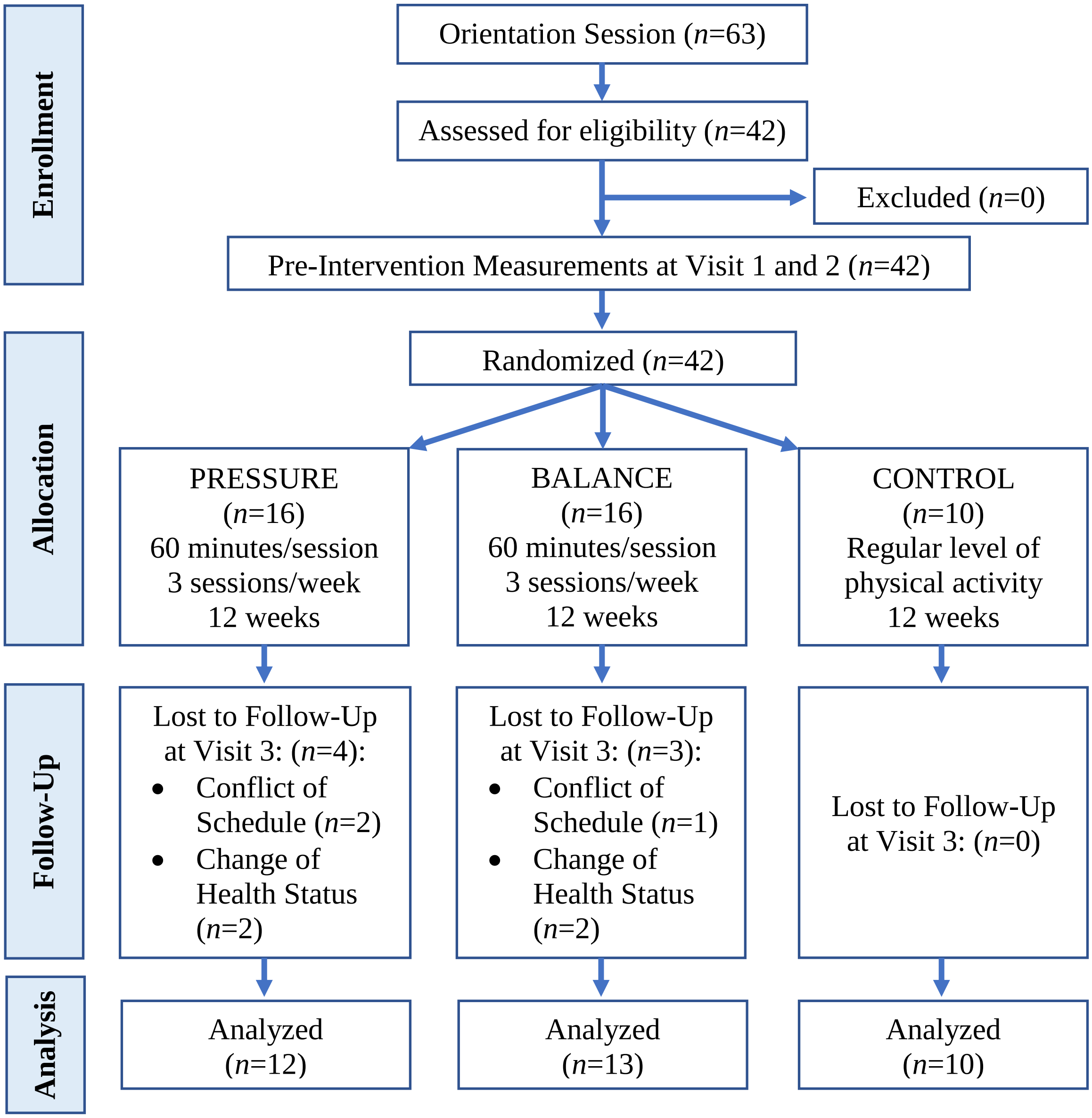

Figure1. Adapted CONSORT Flow Diagram of the Five Phases of Study from Enrollment to Data Analysis

Table 1. Baseline Characteristics of Subjects and the Change of Cardiometabolic Health of PRESSURE, BALANCE, and CONTROL Post- versus Pre-Intervention

	Total (*N*=35)	PRESSURE (*n*=12)		BALANCE (*n*=13)		CONTROL (*n*=10)	
	Baseline	**Baseline**	**Change**	**Baseline**	**Change**	**Baseline**	**Change**
Age (years)	78.9±5.7	76.8±4.6	-	80.5±6.8	-	79.1±5.1	-
Gender (% female)	82.9	83.3	-	84.6	-	80	-
Prescription Medication Use							
Taking Medications	31 (88.6%)	10 (83.3%)	-	12 (92.3%)	-	9 (90.0%)	-
Number of Medications	3.0±2.3	3.1±2.2	-	2.1±1.2	-	4.0±3.2	-
Taking BP Medications	16 (45.7%)	6 (50.0%)	-	5 (38.5%)	-	5 (50.0%)	-
Cardiometabolic Health							
BMI (kg/m^2)	25.9±4.3	26.5±2.8	0.2±1.0	26.3±5.2	0.0±0.5	24.9±4.5	0.2±0.7
Waist Circumference (cm)	88.9±13.0	90.2±10.7	0.0±6.1	87.3±14.2	2.0±5.2	89.4±14.9	0.6±5.0
SBP (mmHg)	126.5±14.4	133.0±11.3	-7.0±11.8	119.9±16.9	-4.2±16.0	127.1±11.4	3.5±8.3
DBP (mmHg)	69.0±8.4	74.1±8.7†	0.6±7.7	66.2±8.9	-0.6±7.6	66.6±3.9	4.1±6.3
Heart Rate (beats/min)	69.3±10.1	77.0±9.1†‡	-2.3±6.9	67.7±8.4	-0.5±5.6	62.1±6.9	-0.3±6.1
Actical Accelerometry (min/d)							
Sedentary Behavior	690.9±99.3	685.0±131.0	-	700.8±85.1	-	684.0±89.4	-
Light Intensity PA	103.2±50.0	94.7±55.0	-	102.4±44.1	-	114.8±54.9	-
Moderate Intensity PA	56.0±32.4	52.9±36.7	-	58.3±30.6	-	56.4±33.2	-
Vigorous Intensity PA	0.0±0.1	0.0±0.1	-	0.0±0.1	-	0.0±0.1	-
Steps per Day	3992.8±2287.4	3563.1±2368.0	-	4515.3±2632.9	-	3763.3±1662.6	-

Note. ***Abbr.*** PRESSURE= Tai Chi Intervention Tailored for Blood Pressure; BALANCE=Tai Chi Intervention Tailored for Balance; BP=blood pressure; SBP=systolic blood pressure; DBP=diastolic blood pressure; PA=physical activity. †= significant difference from BALANCE (P<.05); ‡= significant difference from CONTROL (P<.05); *=significant difference from baseline (P<.05)

Table 2. Baseline Characteristics and Change of Balance, Functional Fitness and Habitual Physical Activity Level of PRESSURE, BALANCE, and CONTROL Post- versus Pre-Intervention

	PRESSURE (*n*=12)		BALANCE (*n*=13)		CONTROL (*n*=10)	
	Baseline	**Change**	**Baseline**	**Change**	**Baseline**	**Change**
Balance						
Single Leg Stance Test (s)	39.9±26.5	-3.3±15.5	38.3±34.3	5.4±18.0‡	34.3±24.4	-8.2±10.3*
Postural Stability Test						
Overall	3.6±1.9	-1.0±1.7	3.0±2.1	-0.2±2.1	2.7±1.8	0.3±1.8
Anterior-Posterior	3.1±2.1	-0.9±1.8	2.7±2.2	-0.2±2.1	1.8±1.8	0.4±1.8
Medial-Lateral	1.3±0.6	-0.3±0.7	0.9±0.7	0.0±0.5	1.5±1.4	-0.1±1.5
Timed Up and Go Test (s)	6.3±1.6	0.0±0.7	7.0±1.6	0.1±1.4	8.2±3.6	0.2±1.3
Four Square Step Test (s)	8.2±1.3	0.1±0.5	8.4±1.9	0.5±1.8	9.1±2.7	-0.2±2.2
Functional Fitness						
Chaired Sit and Reach Test (cm)						
Right Leg	7.5±12.7	0.7±16.4	6.6±10.4	2.0±6.5	5.6±15.9	0.6±4.4
Left Leg	7.5±12.9	-0.5±16.9	7.0±9.9	0.5±7.4	3.7±15.5	0.9±5.2
10-Meter Walk Test (cm/second)	177.9±37.9	12.8±43.3†	186.0±31.8	-24.1±22.4*	164.3±48.4	-14.6±25.5
Hand Grip Test (kg)	8.9±8.2	2.2±2.7*	6.6±3.9	1.1±3.1	10.5±8.9	0.7±2.2
Chair Sit-to-Stand Test (times/30s)	17.7±6.7	1.0±1.8‡	17.4±4.4	1.0±1.7‡	14.6±4.3	-0.6±0.8
Physical Activity Participation Level						
Light Intensity PA (Kcal/d)	109.7±163.6	-9.8±234.2	28.6±73.9	38.6±173.9	130.1±390.5	-52.0±230.0
Moderate Intensity PA (Kcal/d)	889.2±778.3	-144.2±862.8	1184.1±537.4	495.0±1253.0	621.1±585.8	31.7±741.8
Vigorous Intensity PA (Kcal/d)	44.7±127.8	345.8±1372.6	216.4±517.4	-137.3±496.8	84.8±268.2	-84.8±268.2
Sport and Leisure Activity (Kcal/wk)	1967.6±1084.9	-53.1±1630.6	2658.4±617.2	391.4±1469.6	1784.5±753.3	-212.7±980.9

Note. ***Abbr.*** PRESSURE= Tai Chi Intervention Tailored for Blood Pressure; BALANCE=Tai Chi Intervention Tailored for Balance; PA=physical activity. † = significant difference from BALANCE (*P*<.05); ‡ = significant difference from CONTROL (*P*<.05); *=significant difference from baseline (*P*<.05)

Chapter 5. Research Summary

Tai Chi is a low impact,[1] social,[2,3] and enjoyable[4] form of exercise that is particularly suitable for older adults.[5-9] However, Tai Chi is underutilized in the United States (US), a country in which 90% of older adults are physically inactive.[10] Only 2.9% of all adults in the US had life-time experience practicing Tai Chi,[11] and even fewer (~0.8%) are practicing Tai Chi for any specific health purpose.[11] In addition, from 2002 to 2012, the 12-month prevalence of participating in Tai Chi increased slightly 4 % by 0.1 million users, while the 12-month prevalence of using yoga has increased 100% by ~11 million users.[11]

One of the potential reasons for the underutilization of Tai Chi is the lack of support in the physical activity recommendations made by professional health organizations. According to the American College of Sports Medicine,[12,13] the 2018 Physical Activity Guidelines Advisory Committee from the US Department of Health and Human Services,[14] the Canadian Society for Exercise Physiology,[15] the British Heart Foundation Centre for Physical Activity and Health;[16] and the World Health Organization,[17] Tai Chi is recommended only for healthy older adults who are at risk of falling or have poor mobility to improve balance.[12,13,15-17] Meanwhile, no professional health organizations have issued strong recommendations for the use of Tai Chi among older adults with chronic diseases and health conditions such as hypertension, diabetes, osteoarthritis, and Alzheimer's disease. Meanwhile, these diseases and health conditions are among the top priorities of health care for older adults due to their high prevalence and/or their associated adverse health and social-economic consequences. In addition, even though Tai Chi practice varies considerably based on the exercise prescription (i.e., frequency, intensity, time) and the instructional methods (e.g., style, forms included),[18-20] the current physical activity guidelines provide specifications on neither when Tai Chi is recommended.[12,13,15-17]

Almost universally, professional health organizations have stated that the evidence to support the use of Tai Chi among older adults is still lacking for any specific health outcomes other than balance improvement.[12,13,15-17] However, more than 500 interventional studies and 120 systematic reviews have been published on the topic of the various resultant health benefits of Tai Chi from inception to 2016, and the majority of studies have found Tai Chi effective.[21] However, researchers have speculated that such high percentage of studies reporting positive results is partially due to the existence of evident publication bias and the lack of rigorous methodological control in the literature of alternative medicine, including Tai Chi.[22,23]

After we systematically reviewed 27 Tai Chi interventions that examined the effectiveness of Tai Chi to improve balance and meta-analyzed 31 Tai Chi interventions that examined the effectiveness of Tai Chi to lower BP, we have identified two major gaps in the literature. First, the overall study methodological quality was only moderate (63% and 50% items satisfied, respectively) evaluated by the Downs and Black Checklist.[24] Examples of the most common methodological limitations are the lack of measuring and describing study sample characteristics in relation to habitual physical activity level and medication use, and the lack of controlling and disclosing the time between post-intervention measurements and the last session of Tai Chi.[25] Second, several key features of the Tai Chi interventions that are the most relevant to health outcome being targeted are poorly reported such as the intensity, name of the Tai Chi forms included, and the emphasis on movement principles, breathing techniques, and relaxation. Based on our systemic review and meta-analysis,[25] we concluded that what is lacking to inform precise Tai Chi exercise recommendations is high quality Tai Chi intervention studies that investigate the influence of exercise prescription and instructional methods of Tai Chi for the targeted health outcomes being measured.

To address these gaps in the literature, we first designed the Tai Chi Exercise Prescription and Instructional Methods Evaluation Tool (TaCIE) that identified three exercise prescription items and 10 instructional methods items that researchers should consider when designing and reporting a Tai Chi intervention.[25] Then we conducted a randomized controlled Tai Chi intervention study adhering to high standards as specified by TaCIE with all 13 exercise prescription and instructional methods items carefully considered when designing the two Tai Chi interventions and clearly reported.[25] Briefly, we compared the health benefits of two Tai Chi interventions, one intervention (i.e., PRESSURE) was carefully tailored to target BP and included eight Tai Chi forms that required minimum muscular force and excretion to facilitate breathing techniques and relaxation; while the other intervention (i.e., BALANCE) was carefully tailored to target balance and included eight Tai Chi forms that were more physically demanding to provide moderate to high levels of challenge to balance.[12,13,15-17] Both Tai Chi interventions were performed 1 hour/session for 3 sessions/week for 12 weeks among 35 Tai Chi naïve older adults who were highly physically active with balance function well above the average for their age and relatively low and well controlled BP.[26,27,28,29] We hypothesized that PRESSURE would elicit statistically significant greater BP reductions compared to BALANCE; meanwhile, BALANCE would elicit statistically significant greater improvements in balance measures than PRESSURE. Encouragingly, our results showed that Tai Chi improved overall health including balance, functional fitness, and systolic BP (SBP) among older adults. However, contrary to our hypotheses, the health benefits were independent of the type of Tai Chi practice.

Findings from our interventional study suggest that: 1) Tai Chi may provide health benefits to the general population of older adults in the US, who are likely to be less physical active and have less desirable cardiometabolic health, balance, and functional fitness than the subjects in our study;[30,31] 2) professional health organizations should consider recommending Tai Chi to a broader group of older adults than just those who have impaired balance; and 3) Tai Chi naïve older adults may choose any type of Tai Chi practice based on their preference and access to Tai Chi to improve their health. To our best knowledge, our rigorously designed randomized controlled trial is the first to compare the health benefits of two different Tai Chi interventions specifically designed for the targeted health outcome. Of note, the design and reporting of the two Tai Chi interventions were fully in adherence to and rated 100 percent on TaCIE.[32] In addition, we controlled for many factors that were not controlled for in most previous Tai Chi interventional studies such as: 1) habitual physical activity level and medication use were measured and reported; 2) all health outcome measures pre- and post-intervention were performed by the same trained investigator to minimize technical errors and inter-rater variability; 3) all post-intervention measures were performed approximately at the same time of day as the pre-invention measures and between 24 to 48 hours after the last session of Tai Chi to ensure that our results were minimally confounded by circadian variation and acute or detraining effects, respectively;[75,79,80] and 4) all Tai Chi sessions were led by the same certified and experienced Tai Chi instructor to minimize the variability introduced by the differences between Tai Chi instructors in relation to Tai Chi expertise and teaching skills. Future Tai Chi intervention studies should consider adopting such research methods and reporting standards to investigate various resultant health outcomes from Tai Chi among more diverse older adult populations.

The major limitation of our Tai Chi intervention study was the small sample size, which is also a common limitation shared by interventions involving traditional forms of exercise.[33] For example, Pescatello and colleagues found that, on average, an aerobic training intervention would need 225 subjects to be adequately powered to detect significant differences in the change of SBP between the exercise group and the non-exercise control group, and only one out of the eight (12.5%) randomized controlled aerobic training interventions examined was adequately powered.[33] Compared to these traditional types of exercise, a Tai Chi intervention may have even more factors that can contribute to heterogeneous results such as the instructional methods of Tai Chi, and the learning curve of Tai Chi which is still mostly unknown. As a result, Tai Chi intervention that is adequately powered to investigate the influence of exercise prescription and instructional methods over targeted health outcomes would require even larger sample size.

One of the ways to circumvent the limitations of small samples to attain adequate statistical power is through conducting meta-analysis.[34] For example, we recently conducted a meta-analysis examining the antihypertensive effects of yoga. Yoga interventions (k=56) in this meta-analysis included 10 to 238 subjects (62±50), and none identified how the features of yoga may influence the BP response. However, based on the combined sample (N=3517) from the 56 yoga interventions, we found yoga interventions that specifically emphasized both breathing techniques and mental relaxation/meditation elicited SBP reductions of 11 mmHg and diastolic BP (DBP) reductions of 6 mmHg, twice the magnitude of yoga interventions that did not with SBP reductions of 6 mmHg and DBP reductions of 3 mmHg.[35]

Similarly, our meta-analysis that examined the antihypertensive effects of Tai Chi included 31 Tai Chi interventions with a combined sample size of 3223 subjects. We found that Tai Chi interventions published in English elicited SBP reductions of 10 mmHg and DBP of 4 mmHg, half the magnitude of interventions published in Chinese with SBP reductions of 19 mmHg and DBP reductions of 9 mmHg. However, we did not identify any exercise prescription or instructional methods that modified the BP responses to Tai Chi for two main reasons. First, some of the most relevant features of Tai Chi to BP were not adequately reported, such as the intensity of Tai Chi practice (3.2% reported). Second, there was not enough variation in some of the features of Tai Chi among included trials. For example, we were not able to examine the influence of time of Tai Chi sessions over the BP response to Tai Chi because about 80 percent of the Tai Chi sessions lasted 50 to 65 minutes. The results from our meta-analysis support the use of Tai Chi as antihypertensive lifestyle therapy that produces BP reductions that rival or exceed the antihypertensive effects of aerobic exercise of 5-8 mmHg. Meanwhile, this meta-analysis reinforced the need for high quality randomized controlled Tai Chi intervention studies that: 1) rigorously control/adjust for factors that contribute to the heterogeneous results such as accounting for the last bout effect of exercise and adjusting for baseline values of the targeted health outcomes;[33] and 2) design and report the study in adherence to study methodological quality evaluation tools such as the Downs and Black checklist to ensure high internal and external validity.[24] In addition, future randomized controlled Tai Chi intervention studies should: 1) tailor the exercise prescription and instructional methods of Tai Chi for targeted health outcomes; and 2) design and report the Tai Chi intervention in adherence to TaCIE.[32]

Overall, findings from our studies suggest that Tai Chi is a promising lifestyle therapeutic option to lower BP and improve balance and functional fitness for the general older adult population. However, it is imperative for future researchers to conduct high quality Tai Chi intervention studies and tailor the exercise prescription and instructional methods of Tai Chi for targeted health outcomes. As a result, professional health organizations can provide more precise Tai Chi exercise recommendations for specific chronic diseases and health conditions, and ultimately promote the use of Tai Chi among older adults for the resultant health benefits.

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